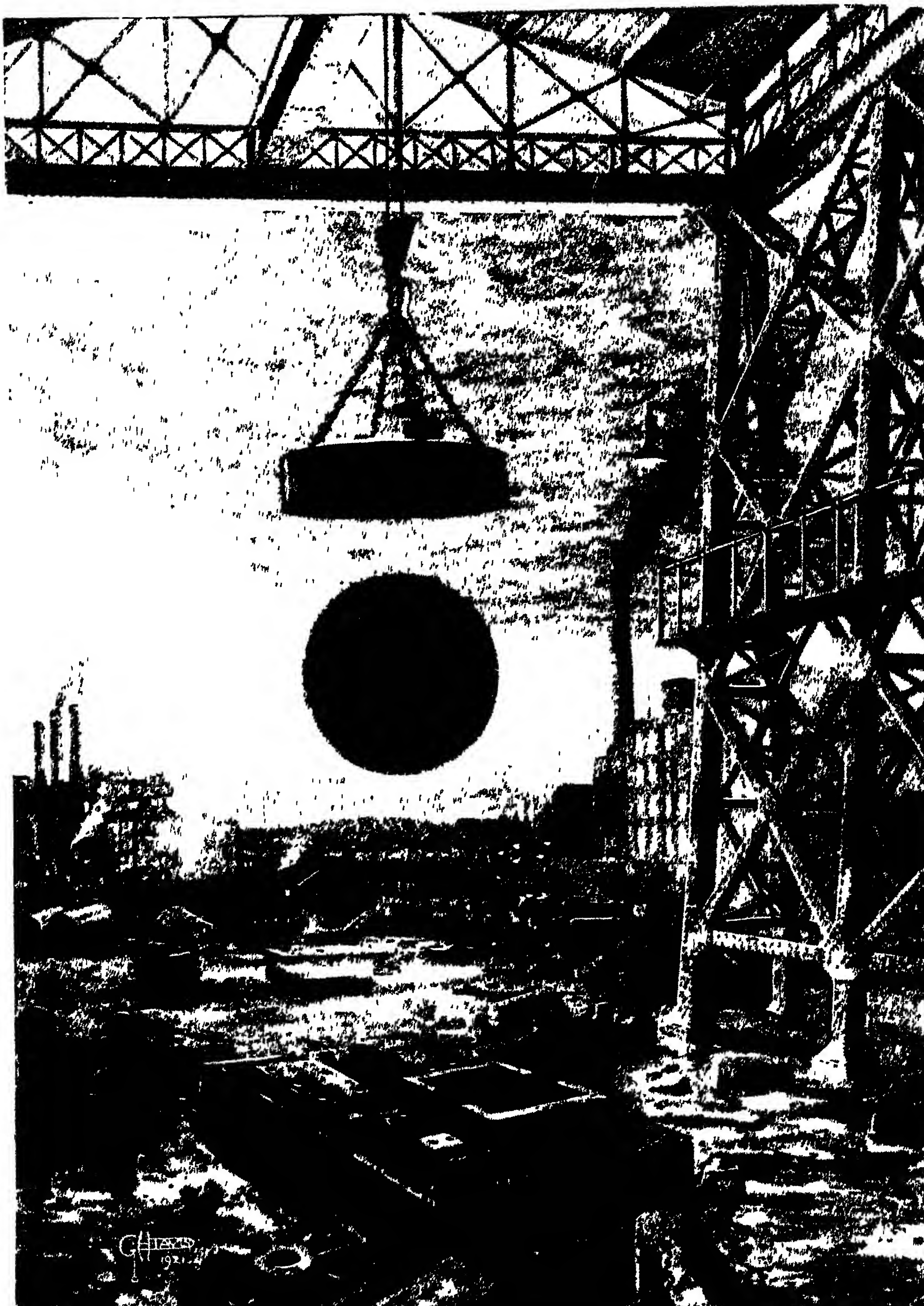

THE FALL OF THE "CRACKER-BALL."

The reduction of large, heavy castings to conveniently sized pieces for the furnace boxes constitutes one of the most spectacular applications of the lifting magnet The solid mass of metal, scaling 30,000 lb or more delivers its destructive blows in rapid succession, and the whole of the work is controlled by one man—the driver of the overhead crane from which the magnet is slung

Electrical Wonders of the World

By

Frederick A. Talbot

Author of "Railway Wonders of the World," "Motor-cars and Their Story," "The Making of a Great Canadian Railway," etc. etc

With Colour and Photogravure Plates, and numerous Illustrations

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LIST OF PLATES

* The diameter of the pipe-line should be 7 feet.

DISCHARGING ORE AT THE RATE OF TWO TONS A SECOND.

Seven Hulett unloaders, working side by side, emptying an ore-carrier of the Great Lakes at the Conneaut Docks of the United States Steel Corporation. On one occasion 11,000 tons of ore were transferred from vessel to rail in 2 hours 58 minutes.

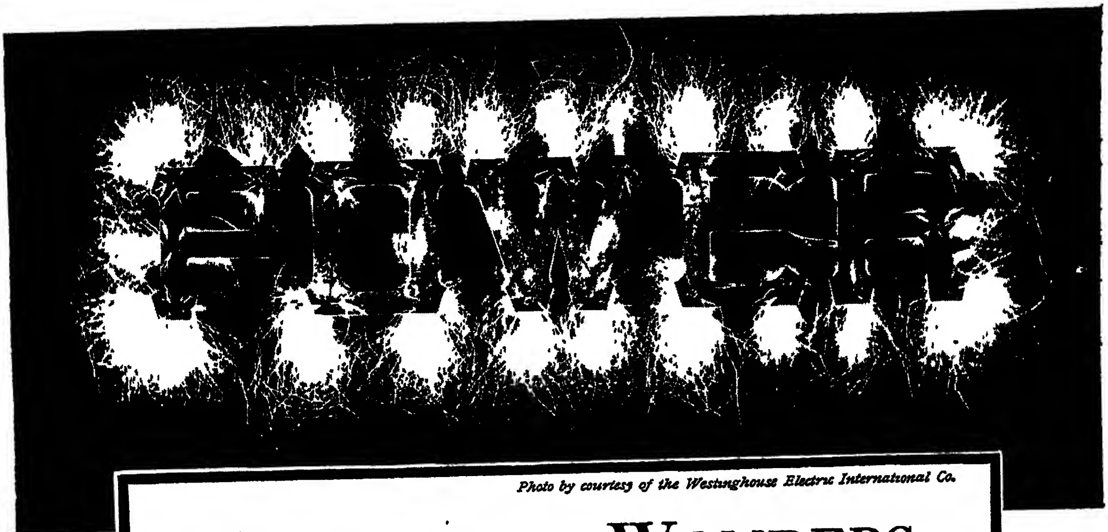


Photo by courtesy of the Westinghouse Electric International Co.

ELECTRICAL WONDERS OF THE WORLD

Foreword

THE dawn of the nineteenth century recorded world-wide recognition of the power and significance of steam. For a hundred years, and more, it has held undisputed sway over our complex industrial and social system, and by its aid many wonderful achievements have been recorded. But to-day we do not extend unswerving allegiance to steam. Its supremacy is being seriously disputed by another form of energy—electricity.

Consideration of the wonderful mechanical era in which we are now living reveals one interesting circumstance. The commercial possibilities and illimitable applications of steam and electricity were appreciated approximately simultaneously, and it appeared as if there would be a spirited race between these two forces for premier recognition. Steam, however, succeeded in drawing far away from its rival, electricity sinking virtually into oblivion for about three-quarters of a century. Such a result, perhaps, was inevitable. Our knowledge concerning electricity was extremely scanty, and its prospects received a decided set-back when the impression gained ground that steam was indispensable for its generation ; it appeared to be a roundabout process to employ the latter for the production of the former, when steam could be employed direct for the supply of power.

Electricity provoked more earnest thought when it was discovered to be unrivalled for illumination. True, the first attempts were crude, but the light thus obtained was so superior to any other, which had been brought to the stage of commercial application, as to induce more searching investigation and concentrated experiment. Electric lighting underwent rapid development, particularly when the practice of generation in bulk at a

central station and the principle of widespread distribution became established. The amazing success recorded in lighting, and the introduction of the dynamo, led to the experimental application of this energy to the mechanical field, first for the operation of stationary machinery and subsequently of vehicles.

To-day we are not dependent upon steam for the production of our electrical energy. We have learned how to generate current by harnessing the tumbling waterfall and the swift tumultuous river. This economic use of a waste force is bringing a revolution capable of illimitable possibilities. It enables us to regard the possible exhaustion of our mineral fuel supplies with equanimity, because the world will not be brought to a standstill thereby as was once feared. The wheels of industry will continue to turn, through the use of a fuel which is inexhaustible, and which is not a wasting asset—rainfall.

The world is becoming rapidly electrified. Even now, although the new force has only risen among us in the course of two generations, we could not possibly maintain our intricate civilization without it. Failing it, communities would still depend upon the semaphore and carrier pigeon, instead of the electric telegraph, for the rapid dissemination of intelligence. In the absence of the telephone, intercommunication in towns and cities —even in buildings—would have to be maintained by speaking-tube or messenger; intercourse between distant parts of the world would be even more exasperating, because the steamship and the post, instead of the cable and wireless telegraphy, would constitute the only links.

Transport would be confined to steam or to some other form of mechanical or animal transport. Rapid transit "tubes" would be impossible. The motor-car would not have been advanced to its present high degree of efficiency, and dynamic flight would have been as remote as it was two centuries ago, but for the magneto and its spark actuating the petrol-engine. It is difficult to conceive such speeds and dense traffic, as now rule upon our railways, without the block system and automatic signalling which are governed by the electric current. Many metals and other commodities with which we are now exceedingly familiar would still have remained mere achievements of the chemist. Except for electricity, should we be able to enjoy such a form of cheap entertainment as the kinematograph offers us?

To relate all the triumphs which have been placed on record by electricity would absorb volumes. The chief object of this work is to record some of the wonders which have been wrought, and in a manner which will assist the reader to realize the extent to which the community is now dependent upon electricity. Technicalities have either been avoided or resolved into simple language. It is not written for the master of craft, although there is possibly much that will interest him.

In preparing the story of the wonders achieved by the aid of electricity, I have been assisted by friends who have been responsible for many of the undertakings described. The arresting illustrations which have been courteously placed at my disposal by the various interests and organizations identified with the electrification of this world of ours add materially to the fascination of the story.

From what is related in the following pages the reader will be able to appreciate how sweeping the great, though silent, electrical revolution is likely to prove. One hundred years ago the community pinned its faith to coal and steam. Within the next few decades it will regard the subtle, mysterious and intangible force which is being carried for hundreds of miles across thin wires as being indispensable to existence. The nineteenth century was the age of steam; the twentieth is the century of electricity.

MAGNETS UNLOADING SCRAP AND PIG-IRON AT A BRITISH STEEL-WORKS.

A 52-inch "Phœnix" magnet, weighing only 5,600 lb., is capable of doing the work of 10 to 15 men.

Lifting Magnets

WONDERFUL LABOUR-SAVING ENGINEERING DEVICES

THESE are the days when the seemingly supremely ridiculous is apt to become translated into stern reality. Accordingly, the assertion that a toy has been converted into one of the greatest time-, labour- and money-saving devices of the present mechanical age, while, perhaps, sounding fantastic, will not be regarded by the average individual as a wild flight of imagination.

The toy in question is the magnet. How many boyhood hours have been spent in following the strange and seemingly extraordinary antics of pins, nails, and other small iron and steel odds-and-ends when brought within the magic influence of the small magnetized loop of steel bought for a trifling sum? Under the impulse of amusement there is a desire to discover the precise possibilities of the tiny device, as witness the tendency "to pile on the load," to attempt to control movement through a sheet of paper or through the table-top!

The true magnet, the lodestone, has been known since time immemorial, but the ability to induce magnetism in common iron and steel by the aid of the electric current is, relatively speaking, a recent discovery.

It was British endeavour, and the inherent characteristic to venture into the unknown, which led to the attempt to harness this power for commercial

purposes, and brought about a result which has proved sensational in its effects. Sheffield is the home of the British iron and steel industry, and among the many establishments in that centre devoted to the working of these metals and their fabrication into the thousand-and-one articles of commerce, are those of Messrs. Steel, Peech and Tozer, Limited.

Among the various duties incidental to such works as these is the stacking of steel rails, billets, girders and other masses of metal against subsequent utilization or delivery, but the handling of such, owing to their weight, dimensions, and cumbersome shape is expensive, especially in stacking, owing to the necessity to leave ample space for the men to attack their tasks. The methods which were in vogue were regarded as being far from satisfactory or economical. Thereupon the engineers set out to discover an improvement if it were feasible. Suddenly, the possibility of impressing the magnet into such service was raised. True, it had been tried before with discouraging results, but that was no reason why another effort in this direction should not be made. A tentative experimental magnet of a new type was contrived, and then the reason for the initial failure was revealed. The contact surface, or face of the magnet to which the load had to adhere, was too small and was not given the most efficient form.

Experiments with the Magnet

An appliance conforming with this fundamental requirement was contrived and generically named the "pot" magnet. It was subjected to severe tests in the steel-yards and, while it proved that the new lines of design were being directed along the correct channel, only partial success was recorded. The reason, however, was speedily determined. The lines of force were unequally distributed, the centre pole exerting the tendency to lift objects two or three deep. The objection to such behaviour when handling stacks of material such as steel rai' was that while the upper layer of rails was lifted satisfactorily, the "digging" effort of the centre pole disturbed the underlayers of material on the bank, rendering it impossible to keep the latter in anything like order.

This was merely a question of design, and so another model was contrived which produced the desired results, and, after considerable experiment, bringing perfection of details, a completely successful model was produced in 1902. This accomplished excellent duty in the yards of the builders, but did not quite fulfil the desires of the engineers, who embarked upon another design, which was forthcoming in the following year. This was a device comprising box-like magnets, or coils, spaced a specific distance apart so as to give ample contact surface to the rail, the poles being connected by a rigid cross-piece or yoke for attachment to the crane-hook. This magnet was designed purely for service in the yards of the Sheffield works, and so was produced along the simplest and most economical lines. That is to say, no trouble or expense was devoted to its finish, the coils being left exposed.

First Successful Model

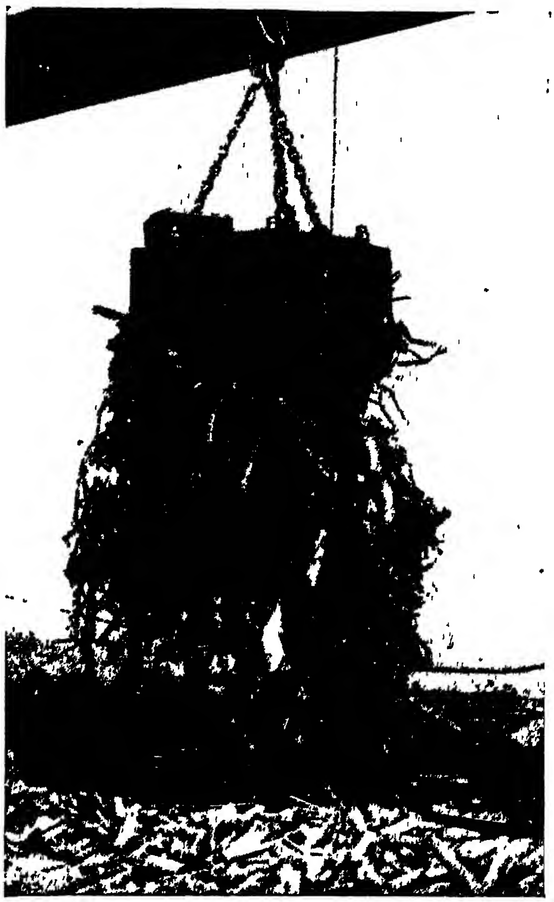
The firm which had embarked upon these investigations had been animated purely by the desire to improve the efficiency of its own works. But ere they had become thoroughly familiarized with the lifting magnet they learned that there was a commercial demand for such an apparatus. The electric crane was coming into extensive use, and the lifting magnet forms an excellent auxiliary to this plant. In this manner what is known as the British "Phœnix" lifting magnet was introduced to the commercial world, the manufacturers being able to support the contentions advanced in its favour by the experience gained in their own steel-works. One important development attended this general request for the device.

Electric Crane in Service

The engineers ·'re quick to realize that a lifting magnet capable of meeting every need demanded variations in design and construction, and the deliberations upon this issue led to the decision to adopt the thin drum or pancake shape, as being most satisfactory for all-round commercial purposes.

This is the type which is in most extensive use, irrespective of source of manufacture. It comprises a circular plate, known as the bumping-plate, formed of non-magnetic and extremely strong and durable metal. Manganese steel has proved to be the most suitable medium for the face-plate and is now generally employed. This takes up all the bumps, jars, jolts and shocks caused by the magnet coming into violent contact with the load to be handled. Behind this is placed the magnet proper enclosed within a heavy casing, the whole being rigidly bolted together. Within the shell thus formed is inserted a central core forming the north pole, while the rim of the drum constitutes the south pole. These are energized by coils placed one within the other in the shell, and maintained a predetermined distance apart. When the components have been secured in position in the shell the whole of the remaining unoccupied spaces are charged with an insulating compound, injected under pressure to ensure absolute insulation and water-tightness, so that the magnet is really transformed into a single solid piece. Eye-bolts are attached to the case to permit slinging from the crane-hook, while a coupling is also provided to lead the current to the coils.

Such form the broad basic principles and method of constructing the commercial form of lifting magnet in most extensive use to-day, the diameter and lifting capacity of which are varied to meet different conditions. Therewith any article fashioned from iron or steel, which is magnetic, may be lifted and carried up to the limits of the magnet's capacity, and also that of the crane in conjunction with which it is used. There is perhaps one exception. Articles of circular section, especially if they be of small diameter, while capable of being handled thereby are not generally recommended as adaptable to movement by the drum type of magnet. The arc of contact between the material and the magnet

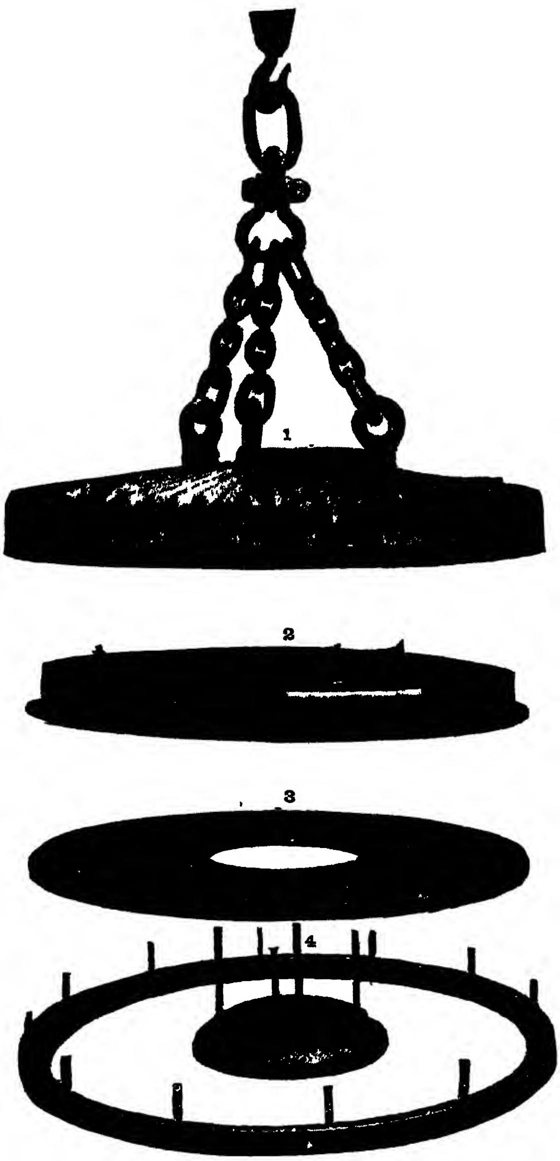


BULK *VERSUS* MASS.
The magnet will lift only 800 lb. or so of this miscellaneous scrap.

face is so slender, especially in the transverse sense, although it may be significant longitudinally. Still, owing to the slight arc of contact exposed, the round rod has the tendency to roll along the face of the magnet. Consequently, when handling articles of round section, especially if they be of decided weight, the use of two magnets coupled together, and spaced a certain distance apart, is recommended, or, prefer-

ably, the use of a magnet which has been designed especially to meet such conditions.

The operation of the electric magnet is the acme of simplicity. When the current



ANATOMY OF A TYPICAL LIFTING MAGNET.
1. Case with suspension lugs, chains and terminal housings. 2. Coil with protective inner plate. 3. Bumping-plate. 4. Pole-shoes with clamping bolts.

is switched on the coils become energized, inducing magnetism at the two poles. When brought into contact with any magnetic material the latter immediately adheres to the magnet, the attachment being far more secure than is possible with slings, chains, or any other method, because the hold is rigid. In this manner the article may be carried and will remain attached to the magnet so long as the current is flowing. When the switch is thrown off and the circuit broken, the magnetic flux dies down, and the load drops clear of the plate. The circumstance that the action is virtually instantaneous, both in attachment and detachment, is of distinct importance, because it enables a charge to be deposited upon, or withdrawn from, a bank with the minimum of disturbance to the underlayers and without the slightest jar.

The latest expression of the "Phœnix" magnet will handle objects of rectangular, polygonal or curved section with equal facility. In this instance the whole design of the familiar model is changed. The pole-pieces comprise two rectangular plates of ample proportions, spaced a certain distance apart, and set vertically. Midway between these two plates is a third and thinner plate of unmagnetized steel, of slightly smaller dimensions, which serves as the suspension plate. On either side of this, and adjacent to its respective pole-piece, is a coil.

This magnet is slung vertically, instead of horizontally as in the case of the drum model, thereby permitting it to handle round and other odd-shaped articles indiscriminately. If moving a single round piece of appreciable dimensions the poles magnetically grip it on either side, the attachment being effected in such a manner as to prevent rolling. If a number of small round pieces are to be handled simultaneously then the magnet is turned round to bring its pole-faces transverse to the longitudinal axis of the load, and in this way a stronger magnetic grip and heavier load can be assured. Another novel feature is the introduction of extension pole-pieces to the lower inside faces of each pole. These are given a curved face so that, if a heavy round piece of steel is being handled, better contact is presented because the curved

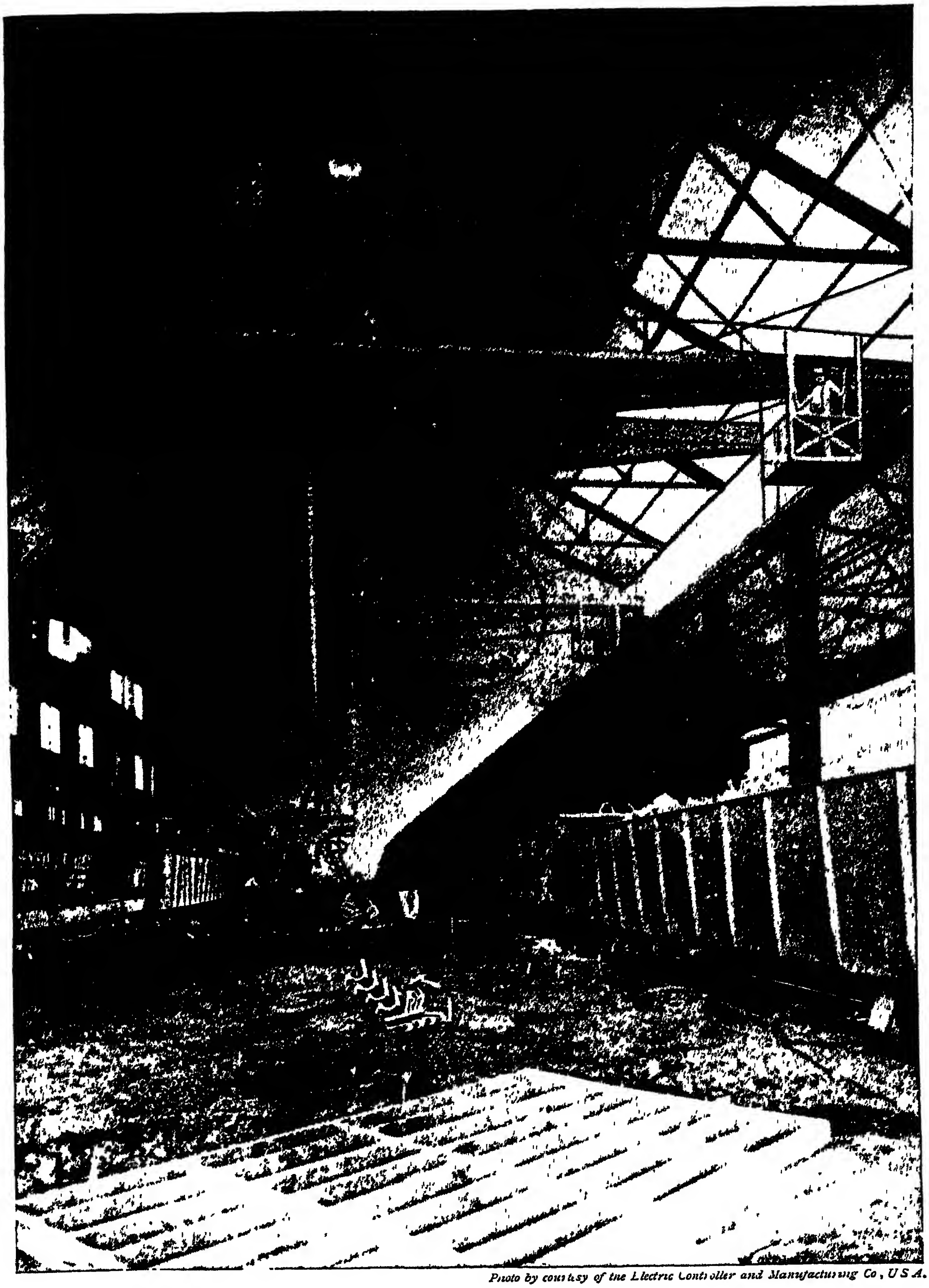


Photo by courtesy of the Electric Controller and Manufacturing Co., U.S.A.

THE MAGNET IN THE FOUNDRY.

It handles castings while they are still too hot to be touched by human hands.

face of the pole-piece extension naturally beds against the contour of the load. These extensions also permit handling of hot material without risk of damaging the magnet in any way.

The Magnet's Dimensions

This magnet measures 24 inches high by 20 inches wide across the pole-pieces, while the over-all depth, that is, the distance between the external faces of the pole-pieces, is 17½ inches. It is exceedingly efficient in moving material from banks. The "digging" effort—that is, the downward attractive thrust of the magnet—is not in the form of a cone as with the circular magnet, but is equal over the entire contact surface. Consequently, the exact quantity of material can be moved from the bank without upsetting the systematic condition of the latter. It will also stack in an equally well-ordered manner, and the piling can be continued to the utmost height which the gantry of the crane will permit.

The lifting magnet is necessarily a heavy unit inasmuch as it must be of robust construction to fulfil the work imposed without derangement, and, at the same time, extend complete protection to its sensitive components. The handling of iron and steel probably constitutes the most exacting service to which any appliance of this character can be exposed. But inherent weight represents so much dead load. Consequently, the higher the limit to which the lifting capacity of a magnet of a given diameter can be raised, in proportion to its weight, the higher must be its efficiency. And it is the accentuated favourable proportion of live to dead load which, at the moment, constitutes the objective of the lifting magnet designer.

The precise influence which large capacity exerts may be gathered from consideration of the performance of the 62-inch "Igranic" lifting magnet, manufactured by the Igranic Electric Company, Limited, although the same feature is characteristic in proportionate degree of the magnets of other diameters issued from the Bedford works of this company. The lifting capacity, that is live load, of the original model was about 2,800 lb. This has now been increased to an average of 4,250 lb. with a current consumption of 72 amperes at 220 volts.

The Magnet's Lifting Capacity

In the operation of the magnet there are three unproductive movements—raising, lowering, and conveying the magnet. Consequently, in the interests of efficiency, it is necessary to counteract the effect of this unremunerative work as much as possible. Increasing the lifting capacity of the appliance achieves this end to a pronounced degree. For instance, assuming that the 62-inch Igranic magnet makes 30 trips per hour, with the high-capacity model, we get a total of 127,500 lb. handled in the 60 minutes, whereas the model which it displaced, although of the same diameter, could handle only 78,000 lb. in the hour. In other words the latter had to make 40 trips to fulfil the work accomplished by the former in 30 trips. Therefore increased lifting capacity involves the employment of fewer magnets to accomplish a given undertaking, fewer operations, and fewer cranes. Under contemporary conditions concerning labour charges and demand for increased output, high capacity upon the part of a lifting magnet is too valuable an asset to be ignored.

British Engineering Enterprise

The study of the lifting magnet has been pursued assiduously for nearly a quarter of a century in Great Britain and for some twenty years in other countries, but although advanced to a high degree of perfection the engineer-designer will be the first to concede that he is far from having attained the complete realization of his dream. While the Sheffield firm of steelmakers were wrestling with the problem and testing their first conceptions in their shops to expedite the handling of their

own production, inventors in the United States of America were devoting their attention to the selfsame problem. Among the pioneers in that country were the Electric Controller and Manufacturing Company, which launched its first model upon the market in 1905—three years after the British firm had brought their magnets into daily operation. Since that year this American company has diligently pursued production at its works in Cleveland, Ohio, and a simple and highly efficient appliance has been evolved.

Prevention of Bumping

The engineers identified with the manufacture of this American lifting magnet speedily discovered, as the result of the investigation of complaints received during the early days of their appliance, that the employment of a single plate between the coil-case and the material to be lifted constituted a pronounced defect. Incessant jarring and bumping tended to work the magnet-plate loose in its case, with the result that that arch enemy of a coil—moisture — effected an entrance and promptly "earthed" it. Even if the craneman attained proficiency in the manipulation of the appliance, and was careful not to bump it upon the material to be lifted, another jarring effect was encountered, from a cause over which he could exercise little or no control—the tendency of the material to jump to the magnet as the latter approaches. This inflicts a hammer blow which, under single plate conditions, was found to be transmitted to the coil within to its detriment. Accordingly, the double plate system of construction was introduced, the outer plate being designed to take up all concussion.

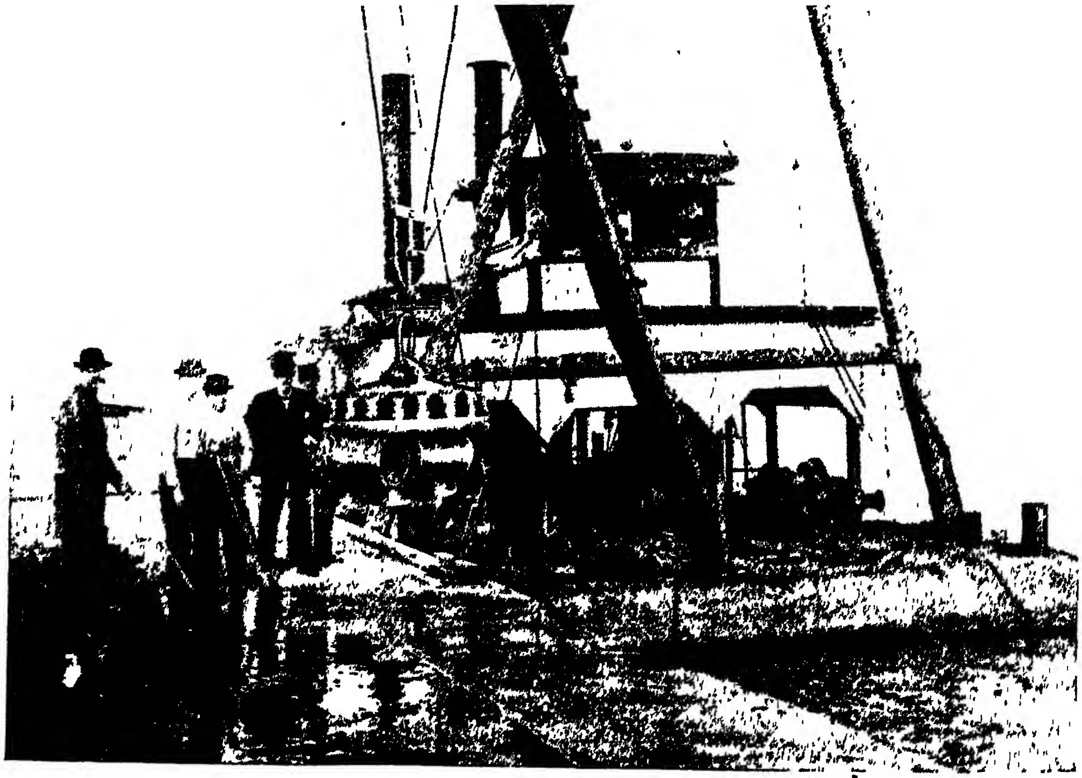
Improvement of the Coil

The American, in common with the British, designers also improved the coil to a very marked degree. Wire, which was the usual material employed, is superseded by copper ribbon, wound on a spool, and with an intervening ribbon of insulating material. In the American magnet in question, the coil, upon being wound, is secured to the brass spool with radial straps. Then the spool is leaded to render it absolutely watertight and secured in its position in the magnet case. To the bottom of the latter the manganese face-plate is bolted. This plate is non-magnetic and fulfils no function beyond that of a protector. Finally, there come the pole-shoes. These comprise a ring bolted to the rim of the casting, and a central core respectively, the central pole being carried through the manganese bumping-plate to exercise its requisite magnetic attraction upon the material to be handled. The shoes are so fashioned and attached as to be readily removed by the release of the clamping bolts and without disturbing the coil or loosening any joints essential to the preservation of water-tightness.

The insulation used in this coil is sheet mica and asbestos with the impregnating compound, thus rendering the magnet fire-proof. All coils after being wound on the spool are subjected to a vacuum impregnating process as in the case of high tension transformers. All empty spaces in the case after the coils have been placed in position are charged with the impregnating compound when all moisture has been expelled.

Current for Magnets

The lifting magnet can be used only with direct current: if the supply available be alternating current this must be transformed into the former for magnet service by means of a motor-generator set or rotary converter. As a rule this appliance is designed to work on a circuit of 220 volts, although it can be built for use upon a lower voltage. On the other hand, if the pressure be higher, such as 440—500 volts, a 220-volt magnet with fixed resistance in series is used, because it has been found that direct working on a circuit of such high voltage is not wholly satisfactory. It is difficult to obtain insulating material capable of withstanding the high inductive



THE LIFTI' MAGNET AS SALVOR.
The "Igranic" magnet has brought up kegs of nails from a barge sunk in 70 feet of water.

reaction which takes place when the [illegible] switch is suddenly opened on the circuit.

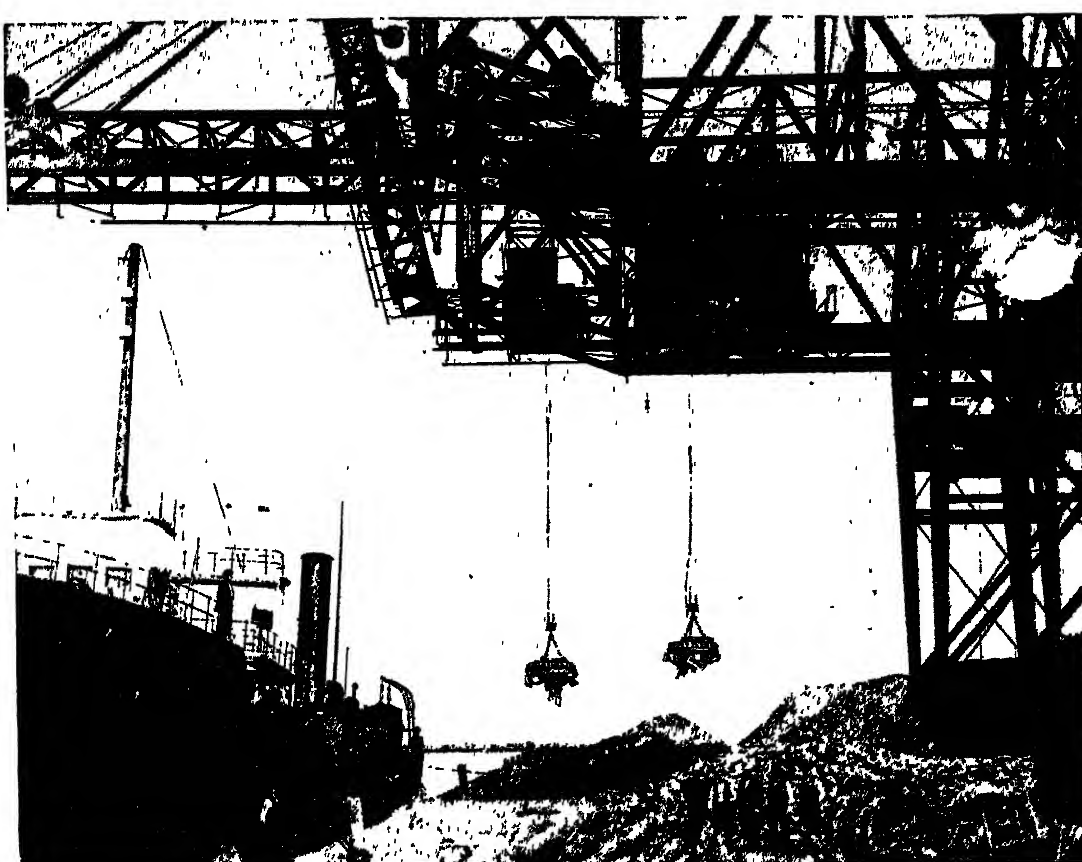
[illegible] ponse of the magnet to the movem[illegible] [illegible]ne switch was stated to be instantaneous. This is not strictly correct, especially in the release of the load, because there is an appreciable interval between the switching action interrupting the circuit and the fall of the adhering material, although the interval is so brief as to make the action apparently instantaneous. When circuit is suddenly broken there is a strong inductive reaction, or "kick," the effect of which is to produce a high voltage at the terminals of the coil. All parts of the latter are affected thereby, and this repeated movement in the convolutions of the coil will break down the strongest insulation in course of time, unless provision be made to limit the induced voltage and to dissipate its energy outside the coil.

What weight will a magnet lift? This is the inevitable question. This factor is wholly dependent upon the character of the material handled. If the latter be in the form of turnings from lathes, it is rather a question of bulk than mass, inasmuch as the turnings—really shavings of steel—are tousled and loose, occupying appreciable space but representing negligible weight. On the other hand, when the material is in the solid form, such as billets and slabs or castings, pronounced weight may become compressed within relatively small space. For instance, the 62-inch American magnet will handle a load of 50,000 lb. when it is in the form of billets or slabs, but the same magnet, when handling turnings or miscellaneous scrap, will lift only 800 lb. or so. These represent the two extremes of the scale between which there is considerable variation according to the material.

Performance is probably the most satisfactory means of judging the possibilities

of the lifting magnet, especially when it is possible to compare its record with that of muscular efforts. Under manual conditions at one American steel-works, to which the pig-iron was brought by steamer, it required the combined service of 28 men for two days and two nights to discharge the cargo of 4,000,000 lb. This represented about 3,000 lb. per man per hour. The steel-works then introduced two "Igranic" magnets which, controlled by two men, moved the 4,000,000 lb. of pig-iron from ship to storage pile in 11 hours! In other words, these two appliances did the work of 28 men in a fourth of the time. The saving of time and labour effected by these two magnets was certainly remarkable, but this did not constitute the outstanding advantage. By their adoption the demurrage of the steamer was reduced to a striking degree, permitting it to cover more round trips within a given time, and thus enhancing its earning capacity. The steel-works in question were so impressed with the performance of these two 62-inch magnets that, at a later date, upon the introduction of the "Igranic" high-capacity magnet, the existing installation was scrapped in favour of two of the more recent and efficient models. Therewith the average lift per trip, which had been 3,427 lb., was raised to 6,000 lb., thus bringing about a still further reduction in the demurrage of the ship.

Reduced to terms of pounds, shillings, and pence, the magnet represents the greatest money-maker yet introduced into the steel-works, because money saved is



THE MAGNET AS STEVEDORE

Some 4,000,000 lb. of pig-iron were discharged from a ship in 11 hours by two 62-inch "Igranic" magnets.

money earned. At one steel-works the cost of unloading pig-iron from railway trucks was formerly performed upon the contract basis, and the figure was 4d. per ton. When the magnets were introduced the cost was reduced to ½d. per ton. In another instance the removal of miscellaneous scrap from railway trucks by hand involved an expenditure of 1s. to 1s. 6d. per ton, but the introduction of the lifting magnet cut this cost to less than one penny per ton!

There is one point which must be borne in mind. The handling capacity of the magnet is governed very materially by the speed and working of the crane with which it is being used. To ensure the utmost return being derived from the magnet, it is important that the crane also should be of high capacity in regard to the essential requirements. Crane speed and character of material exercise a far-reaching influence upon the time- and labour-saving factor. Some of the possibilities of the "Phœnix" magnet, for particulars of which I am indebted to Messrs. E. G. Appleby and Company, Limited, who are responsible for its commercial exploitation, are certainly impressive. In the handling of pig- and scrap-iron a 52-inch magnet of this design, weighing only 5,600 lb., is capable of doing the work of 10 to 15 men. Upon the basis of one trip a minute—60 loads an hour—this magnet consumes approximately 7 units of current, which at the average steel-works costs about ½d. per unit, so that the consumption of current consumed by the magnet equals about 3½d. per hour. A 38-inch magnet handling the same class of material will do the work of 5 to 8 men, consuming 3 units per hour of 60 trips, bringing the cost for current to 1½d. per hour. The special type of "Phœnix" magnet, which has been designed for handling billets, blooms and other similar material ranging from 14 inches to 10 feet in length, will accomplish the work of 6 to 8 men at a cost for current of ¾d. per hour, making one trip per minute. In these instances it will be observed that the cost embraces current consumption only, the variation in the displacement of men being governed by the speed of the crane employed in connexion therewith.

The Magnet a Labour Saver

So far as rapidity of handling is concerned some highly interesting achievements have been recorded by a 62-inch "Phœnix" circular magnet fitted to a 12-ton overhead electric crane commanding a scrap storage ground, the weight of the magnet in this instance being about 7,280 lb., with a current consumption of approximately 50 amperes at 220 volts. In one instance a truckload of steel turnings, which formerly required the combined services of 4 men for 5 hours to discharge, was emptied in 7 minutes! Four large furnace boxes, each measuring 6 feet in length by 31 inches wide and 18 inches deep, placed side by side on a rail lorry, were filled with 4 lifts averaging 1,960 lb. A 52-inch circular magnet of this type, weighing about 5,600 lb. and consuming 40 amperes at 220 volts, handling steel turnings from stock-heaps into railway trucks, made 12 lifts to move 11,700 lb.—an average of over 900 lb. per lift—in 7 minutes. Steel turnings represent one of the most difficult materials to handle, especially if rusted together or with long turnings interlaced. A magnet of this capacity also unloaded 600 tons of pig-iron from railway wagons in 8¾ hours, the operation being controlled entirely by the craneman, no other labour whatever being employed.

Record Achievements

The Sheffield steelmakers responsible for the magnet in question have perfected another design in which the magnet face is oval for the handling of combs of pigs. This is an awkward load to manage. A single round magnet is capable of dealing with the weight involved, but the bed is liable to bend and to break. Before the magnet was introduced for this task from

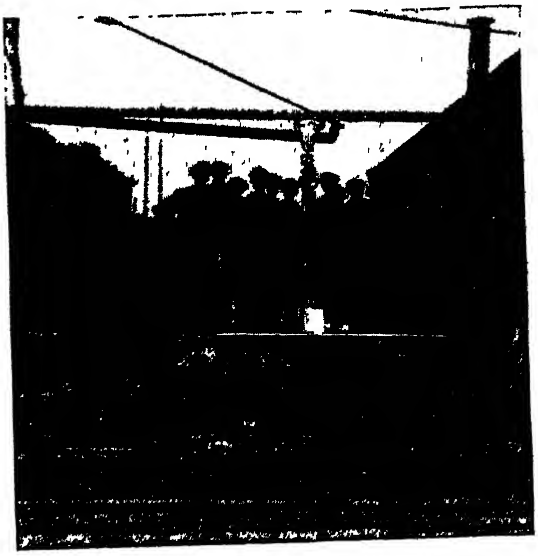
30 to 40 men were required to deal with the bed of 22 combs, the task occupying 4 hours; but since the introduction of the magnet the selfsame work is fulfilled in 16 minutes, and the number of ground men has been reduced to two or three. In order to prove the attractive force of this magnet an interesting demonstration was carried out. Planks of timber, 2 inches in thickness, were placed between the faces of the magnets and the load, but the interposition of the wood did not affect the magnetic attraction in the slightest. Similarly a coating of sand, which is often encountered when dealing with castings, exercises no adverse influence.

The lifting magnet has another conspicuous advantage over the ordinary methods. It can be employed for the handling of any ferrous materials so long as the latter remain magnetic, which property decreases as the iron or steel is heated. Obviously, under manual conditions, castings and ingots cannot be dealt with until they have cooled down sufficiently to allow them to be touched in safety. These requirements, involving appreciable loss of time, do not apply when the magnet is brought into use, because material ranging from 400 up to 600 degrees Centigrade can be handled thereby.

In the foundry this is an important consideration, because it allows the work to be speeded-up very appreciably. Indeed, it may be said to have revolutionized foundry work in all its aspects. This is especially marked in American establishments.

In one foundry, after castings have been made, 2 men first lift the cast-steel cope-flasks. The magnet is then brought along by the overhead crane. It picks up these cope-flasks, 4 or 5 and often more, at a time, moves, and stacks them in a pile on one side of the moulding floor. The castings are then hauled out of the sand by hooks and tipped into another pile. The magnet again comes into action, picking up huge loads of these heterogeneous castings at a time, to bear and to discharge them at the point where the castings are rough-cleaned. The magnet returns to the moulding beds and then pulls out the drag-flasks, which are stacked in the same manner as the cope-flasks.

The magnet is now submitted to another important duty. It is led over the moulding beds and lowered to within a few inches of the sand, when it is swung to and fro



LIFTING CAPACITY OF A SMALL "PHŒNIX" MAGNET.

Twelve workmen raised on a plate 1 inch in thickness.

slowly over the whole of the bed. Any fragments of iron which may be lurking in the sand succumb to the magnetic attraction and jump up to cling to the magnet face. Sweeping and cleaning the sand in this manner is so effective that the latter is seldom passed through a screen to remove the foreign pieces of metal which invariably become associated therewith as the result of the pouring process. This means that the sand is released for further service in less time than would otherwise be the case, while the labour required to attend to the moulding floor is reduced to a negligible factor.

The workshop without workers has for years been the prerogative of the trick

EIGHT TONS OF METAL IN THE AIR.
Two 4-ton ingots at a time were lifted by a "Phœnix" magnet weighing only 15 cwt.

kinematograph film, but we are within closer attainment of this ideal than we may perhaps imagine, at least so far as a specific field of operations in the steel industry is concerned. To-day, it is possible to go into a huge shed, in which railway wagons, charged with a heterogeneous array of scrap, are lined up, and to see the material unloaded therefrom, dumped into stacks or placed directly into the furnace boxes, without a man being seen. A few years ago the trucks would have been swarmed with labourers discharging the loads and filling the hungry waiting furnace boxes.

How has the apparently impossible been attained? By the aid of the overhead travelling electric crane, the magnet, and scientific organization. In such a workshop as this the laden trucks are pushed along the railway tracks. A conveniently adjacent track carries a train of lorries upon which are set out empty furnace boxes. Between the railway trucks and the furnace lorries is a hopper carried upon a portable frame running on rails and so disposed that the chute comes over each furnace box in turn, space being provided for the lorries to pass under the hopper and between the supports of its frame.

In this instance the magnet is even improvised to act as a locomotive. It is lowered over the hopper, and the latter, being magnetic, is pulled along until it is in position at the first empty furnace box. The magnet then hurries away, borne by the crane, to the nearest railway truck, is lowered, grabs a big load of scrap, is lifted and returns to the hopper, into which it disgorges its load. The metal tumbles through the chute into the furnace box, which is filled in the one lift, the hopper is hauled along by the magnet to the second furnace box, when the cycle of operations is repeated. The work is carried out by a single man—the crane driver, who, from his position in his cabin aloft, is not readily visible upon entering the workshop. In one instance, where a modification of this principle has been put into operation, and where the wagons are discharged to stock heaps beside the tracks, all unloading is carried out by the crane and magnet, and one man now controls the work, the whole of which, under the former regime, required 13 labourers.

Nor is the work of the magnet confined to dry land. The circumstance that extreme care is observed to prevent moisture and water penetrating the casing in which the magnet is installed renders it adaptable for the conduct of operations under water down to a certain depth. It has proved to be as excellent and economical a servant in salvaging operations as in the handling of materials in the open air. A ponderous barge, laden with coils of wire, kegs of nails, and other finished iron and steel products, came to grief *en route*, and sank in an American river. When the salvors arrived they found 70 feet of water flowing over the wreck. As the cargo was valuable

it was decided to recover it if at all practicable, but as its salvage by divers and orthodox methods would have been costly and protracted, it was decided to see what could be done with lifting magnets. A number of 43-inch "Igranic" magnets were installed upon the salvaging vessel. They were lowered into the river to sweep the barge, access to the hold of which had been facilitated by preliminary diving operations. The nails were packed in kegs, each of which weighed 200 lb., but each magnet succeeded in putting forth sufficient magnetic effort to secure six kegs at one time, the result being that at every lift the magnet tore 1,000 to 1,200 lb. of the cargo from the wreck. As each lift only occupied a few minutes the recovery of the whole of the magnetic part of the cargo was completed within a very short time, without any loss, and with only slight damage to the goods from rust. As the result of this experiment the magnet is now regarded as an indispensable unit in marine salvage equipment where iron and steel cargoes are concerned.

As a matter of fact, the lifting magnet is now being applied to a variety of purposes exceeding original contemplations, and further new applications are constantly being discovered. It forms part and parcel of the wrecking equipment of many railway systems. After a disaster, in which the rolling stock has been badly smashed and splintered, the magnet is brought forward upon the clearance of the debris from the track to be swung slowly to and fro a few inches above the ground. All fragments of iron and steel—nails, bolts, nuts, screws, and so forth—are instantly picked up and discharged into a scrap wagon standing by. Certain railways use the magnet for picking up and removing old rails, fish-plates, and other material incidental to the track which have been removed and flung to one side by the gangers engaged upon the task of repair. Kegs, boxes, and bags of nails, screws and other articles are packed in huge banks in the warehouses and removed therefrom to railway trucks by this means, the presence of the non-magnetic coverings to the materials not affecting the duty of the magnet in any way. When mixed scrap comprising a combination of iron, steel, brass and copper requires to be sorted, hand labour, formerly held to be indispensable, is virtually superseded. The magnet is brought along and passed over the heap. The iron and steel are instantly separated from the pile, leaving only the non-magnetic metals to be sorted, if desired, by hand.

In its application to industry the lifting

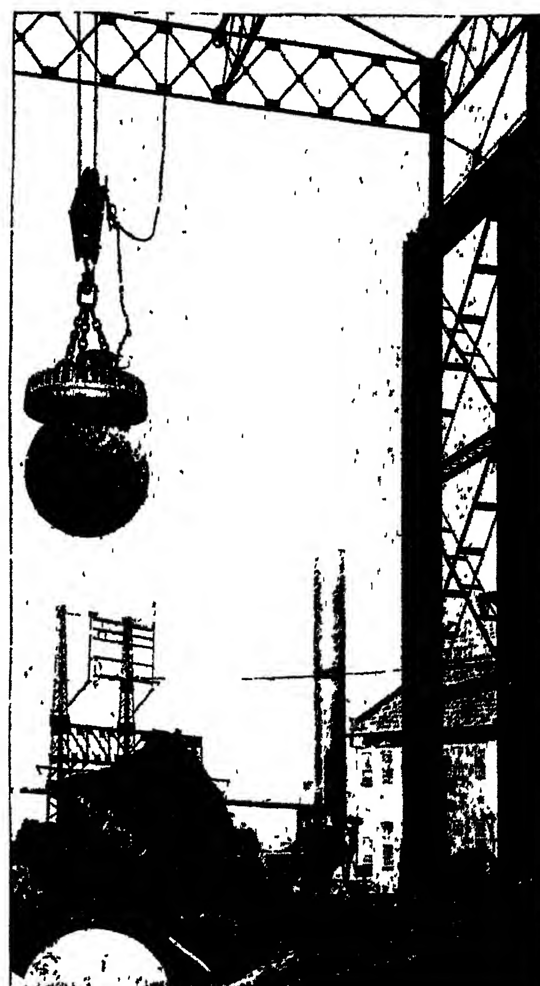


Photo by courtesy of the Electric Controller Mfg. Co., U.S.A.

BREAKING UP THE JUNK.

A "cracker-ball," weighing 30,000 lb., about to be released by the magnet from a height of 50 feet to reduce bulky scrap to small fragments.

magnet has its spectacular aspect. The scrap heap of a large steel-works carries a bewildering assortment of iron and steel articles which have served their commercial end—twisted long lengths of structural steel torn out of demolished buildings, ungainly iron columns, which once supported stately bridges, huge driving wheels, which permitted locomotives to speed along at sixty miles an hour, ponderous boilers, which once furnished the energy to tramp steamers or ocean greyhounds—all the purposes to which iron and steel are applied find their reflexion in the junk pile. Many of these relics are far too bulky to be handled in their familiar form; they must be reduced to more conveniently sized pieces before being re-consigned to the furnace.

The "Cracker-ball"

Demolition is a task which the magnet can fulfil far more expeditiously, cheaply, and easily than any other known disintegrating force, explosives not excepted. Its arm of destruction is a huge sphere of solid steel or iron—a "cracker-ball" or "skull-cracker" as it has become colloquially known—weighing up to 80,000 lb. The employment of this simple cracker is not an innovation incidental to the magnet, because it was formerly employed with mechanical appliances, but under vastly different conditions. It was then fitted with a projecting eye-bolt to engage with the hook of the hoisting chain; it was lifted high into the air by a derrick, and, at the critical moment, was released from the hook by a trigger, to fall freely upon the cumbersome article beneath. After delivering its blow the ball rolled away and generally came to rest with its eye-bolt underneath, rendering the reattachment of the chain-hook a difficult operation.

Now the task is simplified. The cracker-ball, of irregular spherical shape, carries no eye-bolt. The magnet descends and grabs it by pure magnetic attraction. It is lifted to a height of 50 feet or so by the overhead cranes; then the current is switched off. Instantly the released ball drops upon the object beneath. Hard on the fall of the ball descends the mag[illegible] more, swinging to the point to which the ball has rolled. Ere the latter has come to rest it is re-grabbed, and again hoisted into the air. In magnet service the skull-cracker knows no rest so long as there is any smashing duty to be done, and the vo[illegible]ne of wrecking it can carry out in the course of a single working day compl[illegible]eclipses what was accomplished under the former methods. Withal it is safer. Only one man is required to conduct the devastating work, and he is in a safe position—in the cabin of the crane.

A Safety-device

Seeing that it is the steady flow of the current to the magnet which sustains the load, it is obvious that any sudden failure in the current supply must render the appliance inactive. Should the appliance be carrying a load at the time this would naturally fall to the ground. This contingency has been construed into a glaring defect of the system, one which, in the circumstances, it appeared to be impossible to remedy. Nevertheless, British inventive effort set out to meet such an eventuality, if only to permit the load being borne at the moment of current failure to be held a sufficient time to allow lowering to a safe position, if not to its ultimate destination.

Among those who attacked this peculiar problem were the engineers of the makers of the "Phœnix" magnet and, as a result of prolonged investigation and experiment, a simple and effective safety-device has been introduced. This comprises a set of accumulators, connected to an automatic switch, carried on the top of the magnet frame, and the magnet-controller is arranged in such a manner as to place the accumulators on charge each time the magnet makes a lift when, of course, the main current is flowing, and to disconnect it when the moment arrives for the magnet to release its load. In this way the accumu-

lators are kept fully charged. It is impossible for the accumulators to come into operation across the magnet so long as there is main current on the magnet-feeding wires, and the magnet can only be made to release its load at the will of the craneman.

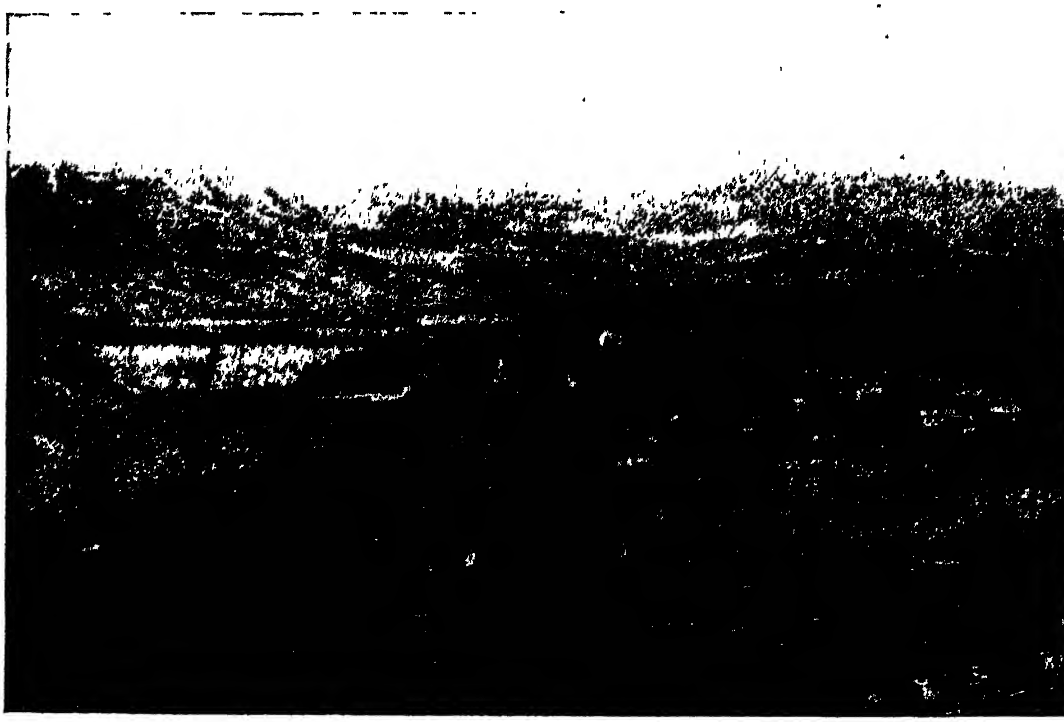
The magnets are made of special high permeability steel which, owing to the main magnetizing current, is capable of retaining its load acting as a "keeper," for some seconds after the main current is switched off, of the residual magnetism to which reference has already been made. The main current failing, the automatic switch is released and the accumulators are put dead across the magnet windings. When the magnet and its keeper—the load—have become saturated by the main current—say 16 amperes—only a small amount of current is required to retain the lines of force which are already set up in the magnet and keeper.

For example, if a load of five tons of steel bars requires a main current of 16 amperes to energize the magnet and to extend an ample margin of safety for carrying such a load, half an ampere is ample to retain the load, while the period which such a load can be retained depends only on the size of the accumulators in terms of ampere-hours. That is to say, a battery of accumulators of 10 ampere hours, giving half an ampere through the windings of the magnet of a predetermined voltage which is supplying the main current, will enable the appliance to retain its load for 16 to 20 hours. The load, of course, can be released at any time at the will of the craneman. It is the usual practice to place a pilot lamp in the circuit to enable the craneman to ascertain that the safety-device is working and intact. He can test the safety-device at any time by pulling out his main switch, when it will immediately come into action and automatically replace itself when the main switch is again closed, restoring the main current supply.

The safety-device is of simple construction and weighs only a few pounds, but efficiency depends to a very marked degree upon the size of the accumulators installed. The elimination of the risk of the load suddenly falling through current failure, which has always been regarded as the weakest feature of the lifting magnet, has enhanced its value considerably.

THE WORKSHOP WITHOUT WORKERS.

A modern British steel-works wherein iron and steel scrap is removed from railway trucks to piles beside the tracks by a "Phœnix" lifting magnet working in conjunction with an Appleby overhead electric crane. This installation is controlled by the one man housed in the crane-cabin.



CREATING A "WATER-FALL" OF 100 FEET.
General view of the temporary town established at Holter, Montana, for the accommodation of the workmen engaged in the construction of the dam and 40,000 kilowatts power-house.

The World-wide Search for Water-power—I

HOW WASTE ENERGY IS BEING HARNESSED FOR SERVICE

CHEAP power is the breath of industry; it stimulates and develops manufacturing activity to the advantage of every member of the community. Appreciating this fact, it is interesting to observe how "fuel fashions" have changed during the passage of the centuries, and to remark how, in this, as in every other realm, there is a tendency for the fashion to move in cycles.

In the beginning wind and water held sway for the operation of mechanism and in the direct sense, as exemplified by the windmill and the water-wheel. Then, with the recognition of the possibilities of steam, came, in turn, wood, coal and oil. With their assistance startling developments have been made, and the map of the world has undergone striking changes as the result of the coincident movement of industry. Now we are witnessing the return to the two natural forces, wind and water, especially the latter, and the development of the water-wheel in a new form. The fashion cycle has not only been completed but restarted.

NIAGARA FALLS AS SEEN FROM THE AIR.

5,500,000 horse-power of hydraulic energy is stored in the Falls, of which only 654,000 horse-power is at present being used Of this total 265,000 horse-power is being generated upon the American bank, and 389,000 horse-power upon the Canadian side, but Canada exports about 125,000 horse-power to her neighbour.

Such a development is logical, economic and scientific. While the search for, and recovery of, coal and oil are becoming increasingly difficult and expensive, the minerals themselves suffer from one fatal defect: they are wasting assets. Water, on the other hand, does not present this disability. No wastage is encountered, for the simple reason that it is merely called upon to dissipate the energy it accumulates when tumbling down the mountain-side or scurrying to the sea in productive work. The engineer is only tapping a natural cycle at a convenient point to achieve his purpose, the generation of electricity, which is the fuel of to-day. In completing his task no wastage is incurred, because eventually the water is released to continue its natural journey. Finally, it must be remembered that water itself traverses an endless cycle, and so cannot become exhausted.

Water-power Inexhaustible

The means adopted by the engineer may appear to be circuitous, even involved, but he is merely demonstrating the truth of the hoary precept, "the longest way round is often the quickest way home." Furthermore, in accomplishing his end the engineer is extending a more valuable service to the race than, perhaps, may be apparent. By harnessing the water to provide cheap and abundant power, he is releasing proportionate quantities of the materials generally recognized as fuels for other and more important duties.

To realize the manifold benefits accruing from such scientific use of water-power as is now being demonstrated, and the widespread, silent revolution which is being wrought thereby, we need only turn to the Niagara Falls, the most familiar instance of striking conquest in this province. Until 1895 Niagara had only one claim to world-wide recognition—the magnificent fall of water which was admitted to be one of the natural wonders of the world. Niagara accordingly became a tourist centre. Then along came the engineer with his sensational scheme for harnessing the water-power running to waste, and converting it into electricity. When the first unit was brought into service in 1895, and 100,000 horse-power were available for the supply of light, heat and power in its most convenient form for all and sundry, a mighty upheaval was recorded. Industry, attracted by the opportunity to obtain cheap energy, flocked to the spot to establish factories devoted to a wonderful diversity of products. Niagara, instead of being regarded only as a show place, became one of the busiest manufacturing centres in the world, and one which is novel withal, for here activity is maintained continuously day and night the whole year round. Thousands of tourists still visit the Falls every summer, but their distributed wealth no longer forms the bedrock of existence to those resident in the district. Electricity is the chief factor of their wealth.

Conquest of Niagara

At the present moment more than fifty staple products are being turned out from the mills planted within ear's reach of the roaring waters, providing raw materials for a bewildering range of other manufactures. It is computed that there are 5,500,000 horse-power of water capable of development at the Falls which, if fully exploited, would be able to fulfil the work of 16,000,000 tons of coal during the year. On the Canadian side, the commercial use of electricity for a thousand-and-one purposes has relieved the citizens of Ontario of the necessity to import 6,000,000 tons of coal during the twelve months!

5,500,000 horse-power

In the State of Montana the volume of electricity supplied by a single undertaking, the Montana Power Company, fulfils as much work as could be performed by 5,500 tons of coal during the twenty-four hours. This represents more than 2,000,000 tons a year, and is equivalent

to more than one-half of the total quantity of this fuel mined within the State during the twelve months. In the course of the first year of operating the 651 miles of its electrified transcontinental line the Chicago, Milwaukee and St. Paul Railway, through feeding its electric locomotives with electricity born of falling water, was able to reduce its fuel bill by 200,000 tons of coal and 800,000 barrels of fuel oil.

Large copper-smelting plants at Butte and Anaconda, 130 and 150 miles distant respectively, are operated by current at 110,000 volts transmitted from the famous Rainbow Falls on the Missouri. Power supplies of 35,000 kilowatts capacity are drawn from the Falls.

Californian Enterprise

Water-power, by its conversion into electricity, has saved the State of California; but for this provision of Nature, the ingenuity of the engineer, and the faith and enterprise of its citizens, this corner of the sunny Pacific coast would have languished. The population was forced to embrace hydro-electricity to secure its preservation. There are no domestic coal deposits; every ounce of this fuel must either be hauled across the continent or be imported from British Columbia or Australia. Industry was handicapped by the heavy cost of this indispensable handmaid, due to the long transport and the fact that the two main sources of supply were outside the country, involving the payment of import duty.

The situation was relieved to a certain degree upon the discovery of petroleum which, when the Californian fields burst dramatically into production, could be bought in Los Angeles for about a shilling a barrel. Oil naturally commanded instant attention in local industrial circles, because liquid fuel at such a price was equal to the very best grades of bituminous coal at four shillings a ton—a hopelessly impracticable figure. Unfortunately, this happy state of affairs did not reign for long. The oil-producers could not afford to sell the commodity at such a price—it represented a dead loss, but, as the accumulations were formidable, clearances had to be effected. Directly the oil-fields were brought under control and pipe-lines were laid to permit the petroleum to be shipped to all parts of the world, the price of the fuel began to rise. Within a short time three shillings a barrel was demanded in Los Angeles and four shillings a barrel in San Francisco. Coal and oil were now placed upon a more equal footing, and, as the price of the former continued to soar, carrying the quotations for oil with it, industry was compelled to take stock of the situation. Either another form of energy must be discovered and turned to account, or local manufacturing endeavour must suspend operations, through being disadvantageously situated in regard to competition for markets.

Transmission Wonders

To save the situation the engineer was encouraged to give full rein to his imagination, while the purse strings were released to enable him to materialize his dreams. As the result, many electrical wonders have been consummated in this State, which is now recognized as the leader in all matters pertaining to hydro-electrics. Huge strides have been made, not only in the fulfilment of striking engineering undertakings for the impounding and storage of the necessary water in the depressions among the mountain peaks, the harnessing of the swiftly running and falling rivers and the equipment of power-stations, but in regard to the construction of "express" lines for the through transmission of the energy generated in distant plants to the humming cities where the power is so urgently required. Some of these lines run up to 200 miles and more in length.

Distance is only one phase of the wonder aspect. It is paralleled by the enormous pressures at which the current is carried,

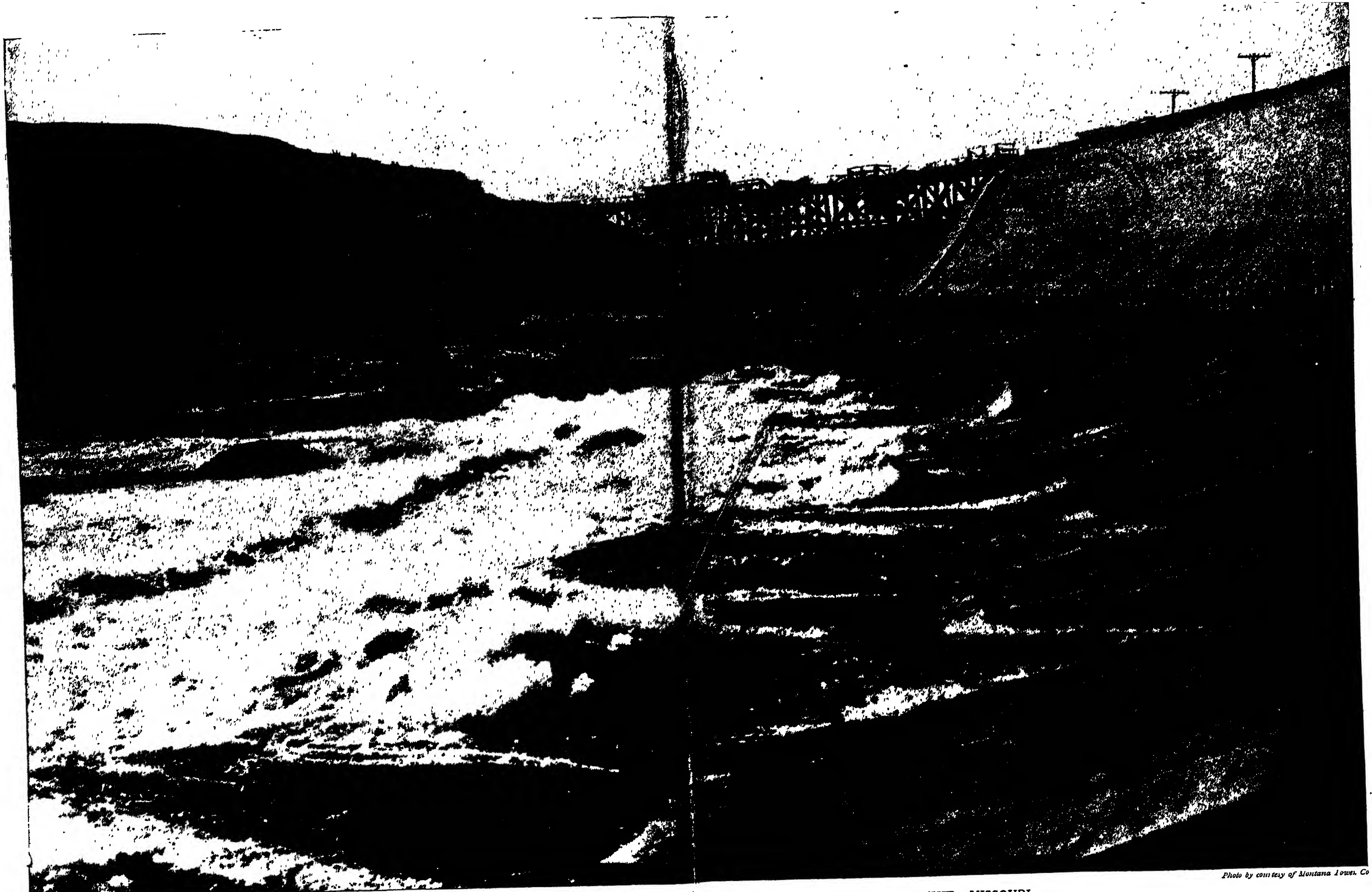
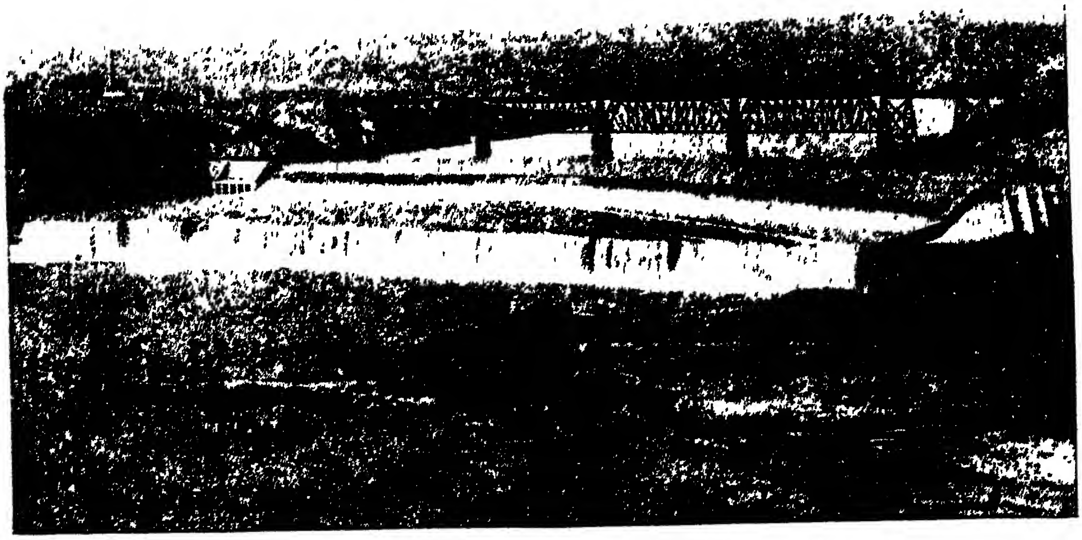


Photo by courtesy of Montana Power Co

THE HYDRO-ELECTRIC ENGINEERS' CONQUEST OF THE GREAT FALLS OF THE MISSOURI.

To permit the construction of the huge dam one half of the waterway was closed at a time. This photograph shows the first section of the concrete barrage completed on right; through the temporary sluices the turbulent waters are rushing The opposite half of the river bed is laid bare, and operations are shown in active progress.



GENERAL VIEW OF RAINBOW FALLS AND DAM ON THE MISSOURI

The timber crib dam seen above the Falls measures 1,145 feet in length by 36 feet in height. 35,000 kilowatts are drawn from the river at this point.

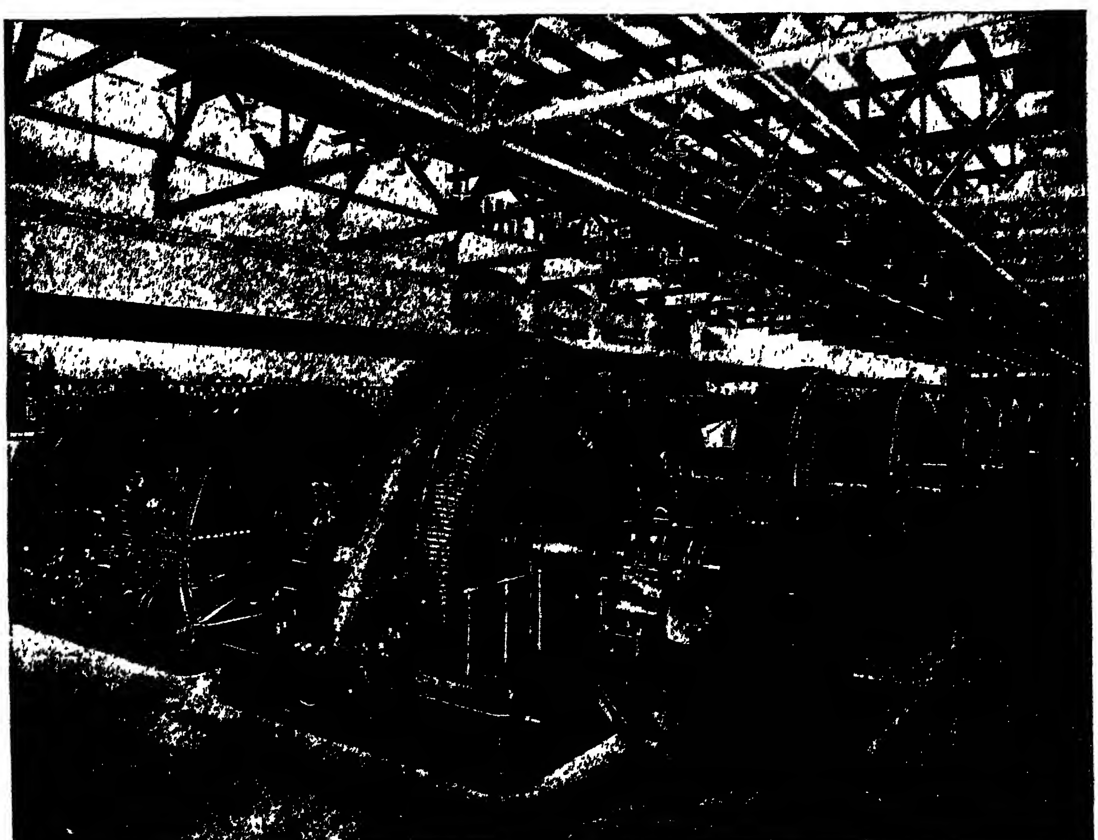
and which thirty years ago were regarded as being fantastically impossible. Pressures of 110,000 volts are quite commonplace, but already lines are being built to transmit current at 220,000 volts. Precisely what this means may be gathered, perhaps, from the fact that the pressure maintained in the overhead conductor strung through our streets for the operation of electric tramcars is only 500 volts! The adoption of such tremendous pressures is being forced upon the power companies by the insistent demands for cheap electricity—claims which appear to defy satisfaction.

No matter where one may turn, if water-power be available, huge plans are being formulated and discussed to convert it into electricity. The movement is world-wide, and the countries endowed with this resource are taking full stock of their heritage. Elaborate surveys are being made of all the cascades and swiftly running waters, from the noble river forming possibly the main marine link through the country, to the fussy bubbling mountain stream. At the same time sweeping laws are being placed upon the statute books of the various nations to ensure the preservation of the resources, and all the benefits they can possibly bestow, for the citizens, and to frustrate haphazard and erratic development which would inevitably lead to waste and abuse.

When the electrical engineer conclusively demonstrated that the Niagara Falls could be tamed there was a keen rush for hydro-electric rights. Had all the schemes advanced been carried to maturity, Lake Erie would have ceased long since to empty its waters into Lake Ontario by way of the famous cliff. The water would have been trapped and led through an amazing network of canals and pipe-lines to actuate ponderous turbo-generators. But the chain of lakes and the St. Lawrence River form a section, several hundred miles in length, of the boundary between the United States

and the Dominion of Canada, and both countries share this natural fence.

The situation was somewhat peculiar. Development was proceeding most energetically upon the Canadian side owing to the fact that seven-eighths of the total volume of water tumbles over the Horseshoe Fall, but the work was being prosecuted for the most part by American companies armed with American finance, and the power thus generated was being exported to the United States. Strenuous efforts were made to circumvent this peculiar trade movement. It was effectively checkmated by the introduction into the United States Congress of the quaint bill known as the Burton Act. The purpose of this projected legislative measure was declared to aim at the preservation of the beauty of the Falls, but when closely scrutinized it was found to be much more subtly far-reaching, because it set out to arrest all further diversion of water by prohibiting the importation into the United States of electric power generated upon the Canadian side of the waterway, over and above the contracts in force at the time. As this brought about the elimination of the American consuming market all inducement to develop further power on the Canadian side was scotched, and so the Act accomplished its purpose. Subsequently the United States and Canadian Governments came to close grips over this issue. The outcome of those deliberations was the decision to exercise mutual control over all further speculation in hydro-electric energy, not only at Niagara, but at every other possible site along the water sections of the frontier line. The



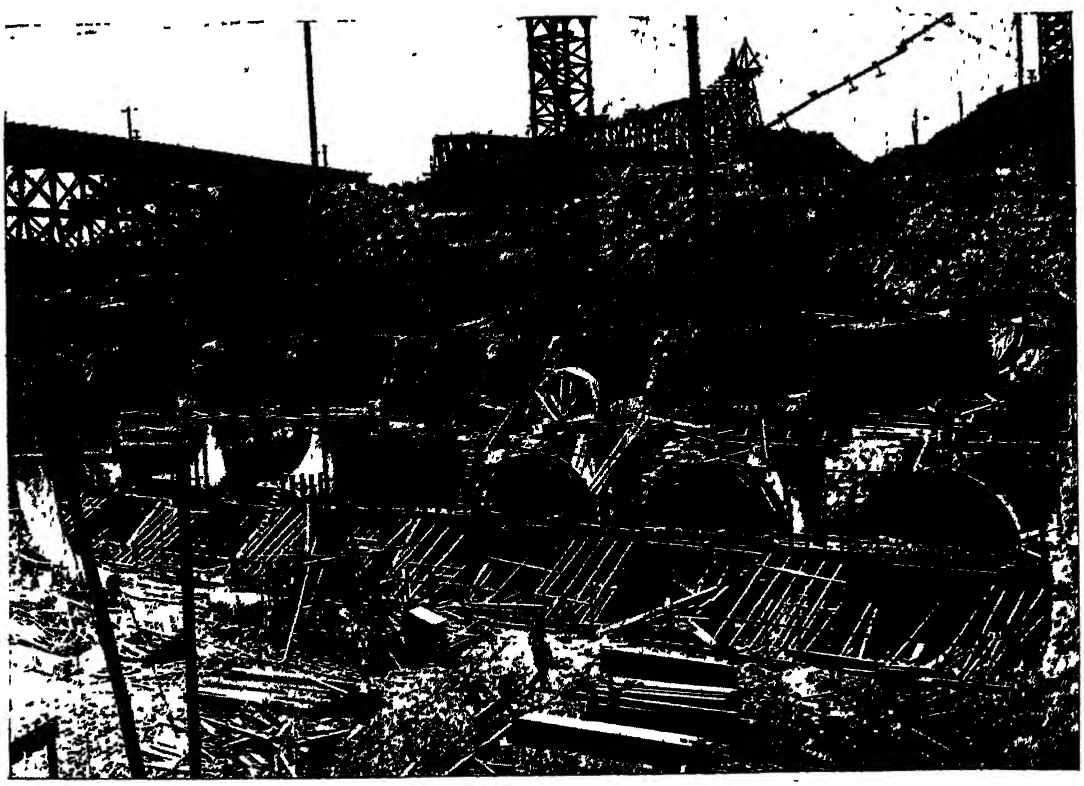
GENERATING STATION OF THE ONTARIO POWER CO., NIAGARA FALLS.

The station, which is shown below the Falls on the right-hand side of the picture on p. 17, is capable of developing 238,500 horse-power under a head of 180 feet.

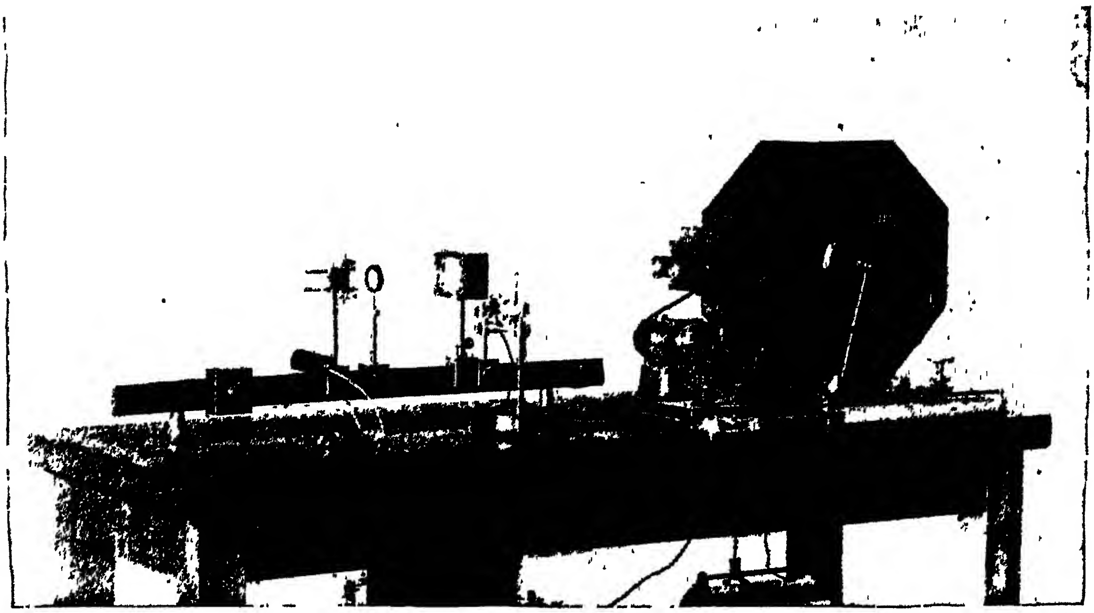
net result of these diplomatic discussions was the decision that, of the 5,500,000 horse-power of water tumbling over the famous ledge, only a maximum of 2,500,000 horse-power was to be diverted for the generation of electricity, and proportionately upon either bank.

So far, the two largest waterfalls in the world have not been taken in hand for their hydro-electric wealth, although projects for the exploitation of a certain proportion of their power have been prepared. These are, respectively, the Victoria Falls on the Zambesi River, and the Iguassu Falls on the river of that name entering into the boundary between Argentina and Brazil. The first-named is the world's greatest wonder; it is over a mile in width, and the river makes a single plunge of 383 feet. The energy tumbling over this ledge is stated to aggregate 35,000,000 horse-power at least, which is approximately equal to the whole of the hydraulic energy contained in all the waterfalls of Europe. The Iguassu Falls rank second in point of dimensions and potential power, being about 2 miles wide and 213 feet in height, and presenting, it is estimated, 14,000,000 horse-power. Both these falls are at present safe from development, because they are far distant from the beaten tracks of industry.

Some of the spectacular waterfalls of the world are preserved against the ambitions of the hydro-electric engineer in perpetuity by inclusion in national open spaces and consequent dedication to the public. Such an instance is offered by the Yosemite Fall, which drops 2,600 feet in three imposing steps. Situate in the Yosemite Valley, 140 miles from San Francisco, which was declared a public park thirteen years after its discovery, this cascade is certain of preservation for all time.



A HYDRO-ELECTRIC POWER-HOUSE IN THE MAKING.
Setting the draft tubes through which the water of the Great Falls of the Missouri is returned to the waterway, after falling 150 feet to drive the turbines.



APPARATUS FOR FILMING THE FLIGHT OF INSECTS.
Bees, wasps and dragon-flies are kinematographed at the rate of 1,500 to 2,500 pictures a second.

Taking 25,000 Moving Pictures a Second

SHOWING HOW SCIENTISTS HAVE ADAPTED THE KINEMATOGRAPH

SOME forty years ago, a French professor of physiology, Etienne Jules Marey, became absorbed in the study of motion in its infinite variety. To be able to pursue the analysis and synthesis of movement under the most favourable conditions he founded a small laboratory in a picturesque suburb of Paris, and here, by impressing photography into his service, he contrived much wonderful apparatus for the fulfilment of his studies, the results of which he projected in animation upon the screen.

These contributions to science were invaluable. Upon his death it was found that he had made arrangements for the perpetuation of his work. The Marey Institute, which is supported by every country, is still continued along the lines inaugurated by its founder—experiment and research; and it may be remarked that many of the discoveries made at this institution many years ago are now being incorporated in the production of the popular moving pictures.

The Marey Institute is the cradle of kinematography; its privileged personnel is always seeking further conquests in the world of movement. The active direction of this small force of scientific workers is fulfilled by an Englishman, Mr. Lucien Bull, whose fertility of thought in this highly specialized field appears to be inexhaustible. I have spent many hours with this enthusiastic kinematographic

scientist and motion explorer, following him through many of his complex experiments, the results of which, when thrown upon the screen, while amazing, do not convey the slightest idea of the time and labour expended in their preparation. Surely it is remarkable to be able to catch a bee in flight, and to reveal the action of its wings upon the screen, or to reduce the apparent velocity of a shell or bullet hurtling through the air to a pace comparable with the crawl of the tortoise!

To grasp what such an achievement really

THE "BULL" CAMERA.
Showing twin lens, interrupter and dual rims upon which the films are mounted.

signifies, it is necessary to remark that the familiar picture-play is photographed and projected upon the white wall at the rate of fourteen to sixteen pictures per second, this being the *minimum* possible to delude the human eye and brain, in accordance with the law of visual persistence, because moving pictures are a sheer illusion. The minimum cited has become established solely from commercial motives, to reduce the consumption of the necessary sensitized celluloid ribbon to the lowest figure. Pictures taken at twice the speed mentioned would yield a far more perfect result, but the improvement to the normal eye would be so slender, if it were perceptible at all, as to render the additional expense superfluous.

Nevertheless, when it comes to the kinematographic record of a bee, dragon-fly or moth in flight, to follow the action of the delicate wings, orthodox methods and apparatus are hopelessly impossible. Such work therewith would be akin to essaying to empty the Atlantic with a tea-cup. The oscillation of the wings of insects is incomprehensibly rapid. The human eye cannot possibly follow the motion; knowledge that the wings are flapping is revealed only by the distinctive musical hum resulting from the excessive air vibrations thus set up.

When Mr. Bull essayed to catch an insect in flight to analyse the action of the wings, he realized that he would have to evolve special apparatus for the purpose. In conjunction with his mechanical colleague, M. Noygues, he made one experiment along the orthodox lines, building a camera similar to that in general use, but with which 240 exposures a second could be made; however, it proved serviceable only in a severely limited field of research.

Forthwith he embarked upon the construction of a camera which has nothing in common with that ordinarily used for kinematographic work. It has many highly interesting and ingenious features, and to achieve his end the investigator was forced to have free recourse to electricity. The instrument in question comprises a thin cylindrical wheel or drum fixed upon a shaft supported at either end by a bracket bolted to a base-plate to ensure rigidity. This wheel is 13½ inches in diameter and carries two rims, the surfaces of which are perfect planes and set a certain distance apart.

Round each of these rims is placed a length of sensitized celluloid film, each band measuring 42½ inches in length, and corresponding to the circumference of the wheel. Standard film is employed and the

length adopted is sufficient to give 54 consecutive pictures of normal dimensions during a single revolution of the wheel. The shaft upon which this drum is mounted is fitted with an interrupter disk, which is also keyed to the drum-shaft so that it revolves with the latter. The drum, or film carrier, is placed in an octagonal box, the upper half of which is hinged to the lower section to permit easy access to the carrier for the attachment and withdrawal of the film lengths.

Upon the front vertical side of the octagonal camera the lenses are mounted. This attachment is really a reflex adjunct, similar in design to that of the familiar hand-camera of this type and fulfilling the self-same function, namely, the focusing and composition of the picture. But the mirror, instead of being automatic in its operation, is controlled by a milled screw. When all preparations have been completed, the milled screw is released and the mirror swings up to bed firmly against the ground-glass to form a light-tight joint.

How the Film is Exposed

Another departure from conventional kinematographic practice remains to be explained. In the familiar camera the movement of the film is intermittent; that is to say, it is jerked forward $\frac{3}{4}$ inch after each exposure, the lens being obscured by the blade of a revolving shutter during the fraction of a second in which the movement of the film is made. In the "Bull" camera the lenses are left uncovered during the whole period in which the film wheel within is completing its revolution, the motion of the latter being continuous through that revolution. Accordingly special arrangements had to be devised to ensure the two lenses being "uncapped" at the instant the cylinder commenced to revolve, and "re-capped" upon the revolution being completed, to avoid fogging of the film, or possible superimposition of further images upon those already obtained. Obviously, under the momentum imparted, the drum will not stop dead upon completing its rotation.

The Shutter

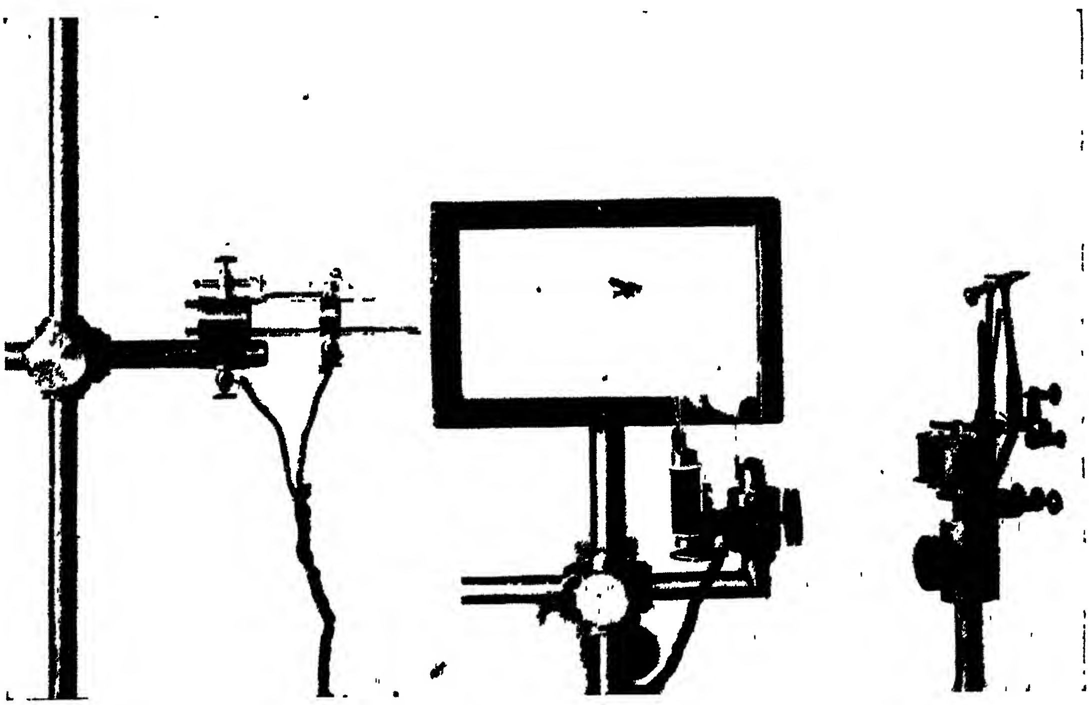
To meet this condition a special simple shutter was contrived. It comprises a thin sheet of brass, pierced with two openings coinciding in dimensions with the image recorded, and set close to the film. When the camera has been charged with film these openings are covered by a thin piece of steel, forming a curtain, held in position by means of an electro-magnet controlling an extended spring. Above is a second and similar curtain. When the cylinder commences to revolve, or when it is desired to make the exposure, an electric impulse is discharged through the electro-magnet. This releases the spring holding the first curtain in the closed position and allows it to fall into a position below the apertures. The lenses now uncovered allow the exposures to be made. The moment the drum has completed its revolution a second electric impulse is discharged through the electro-magnet, and this releases the spring holding the second curtain which falls and drops over the apertures of the lenses.

Lighting the Subject

Owing to the high speed at which the exposures have to be made, the orthodox systems of lighting the subject, no matter how elaborate or brilliant they may be, are useless. For such work the electric spark is indispensable. While the spark only sheds a relatively small volume of light, it is intensely luminous and rich in the rays essential to photography. The electric spark is produced intermittently, although at regularly recurring intervals, while the number of sparks discharged within a given time can be varied at will. In the earliest experiments the number of exposures were about 2,000 per second, necessitating the discharge of a corresponding number of sparks within the specified interval of time.

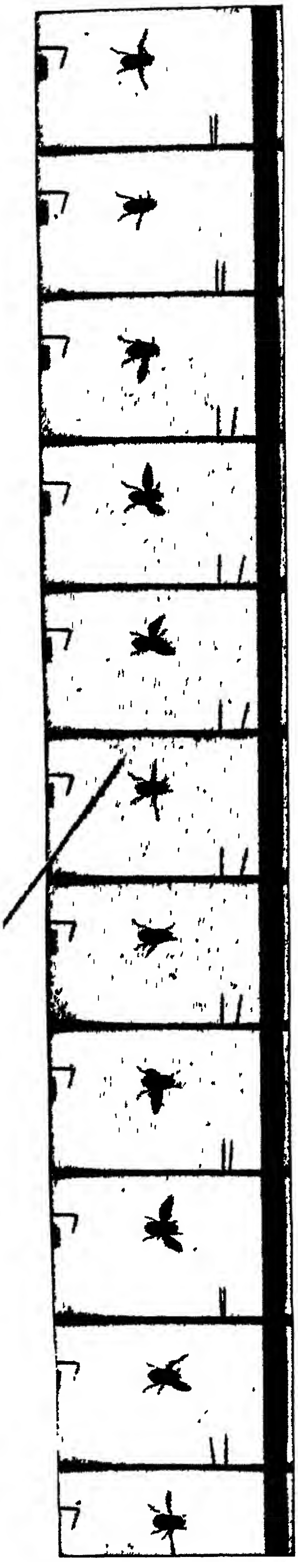
The spark, about $\frac{1}{25}$ inch in length, is struck between two magnesium pointed electrodes about $\frac{1}{12}$ inch in diameter. Its intensity is augmented by the introduction of a small condenser placed in parallel with the secondary circuit. The occurrence of the spark is governed by the interrupter mounted on the film-drum shaft. Consequently, although the film-drum is given a continuous motion—an electric motor is used for this purpose—and the lenses are left uncovered during the period of the revolution of the film-carrier, it will be seen that the regular successive striking and quenching of the illuminating electric spark fulfils exactly the same purpose as the momentary obscuration of the revolving shutter in the ordinary mechanically operated kinematograph camera, and so produces intermittent exposure. The pictures are taken in such rapid succession that there is no risk of the film being fogged by surrounding illumination, while similarly, owing to the positive action of the shutter, operated by an instantaneous electric impulse, there is no risk of exposure overrunning the end of the band.

Having completed the camera, the next problem to be surmounted was the control of the elusive diminutive subjects concerning the movement of which scientific data were sought. This was a question of quite a different character. It was imperative that the studies should be in unfettered command of their liberty while being kinematographed so that the recorded action should be perfectly natural. At the same time it was equally necessary that the insects should be under some semblance of control to assure the flights being made across the field of the lens. Furthermore, as the length of film is only $42\frac{1}{2}$ inches, to expose which at the rate of 2,000 pictures per second occupies but an infinitesimal fraction of time, it was essential that the exposures should not commence until the insect was fairly on the wing, and within the field of the lens.



THE INSECT'S AERODROME.

A bee is seen escaping from the ingenious tube trap on left and crossing the photographic field of the "Bull" high-speed kinematographic camera.



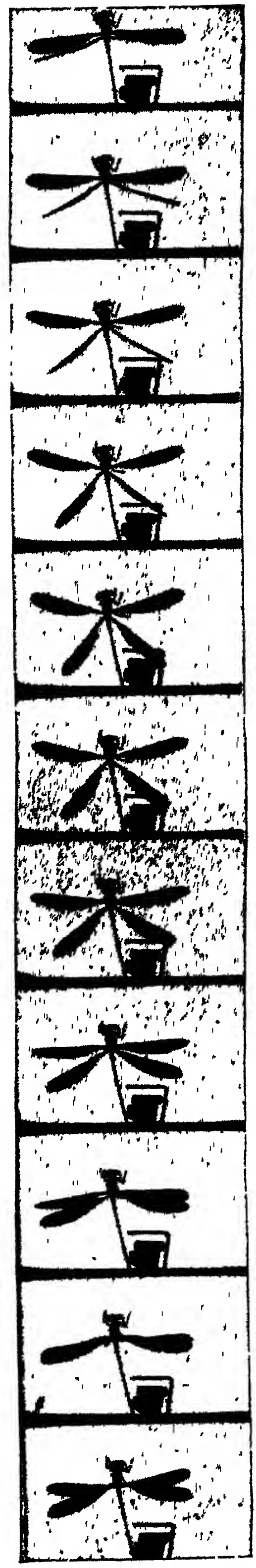
HOUSE-FLY IN FLIGHT.
Recorded at the rate of 1,800 photos per second.

To fulfil these conflicting and exacting conditions involved a preliminary study of the insects' habits and peculiarities. These proved somewhat interesting. It was observed that whereas some insects speed away the instant they are released, others pause for a fraction of a second, as if uncertain, or completing preparations for their flight. It was also noticed that all insects instinctively fly towards the light. Obviously some means of holding the study captive for release at the critical moment had to be devised; release from the hand was too clumsy and uncertain, as well as being liable to damage the frail fabric of the insect's wing.

The ultimate resolution of the problem, which was attended by many aggravating failures, is novel. It completely fulfils every requirement, ensures the insect traversing the designed optical field ninety-nine times out of one hundred, secures the study in full flight, and assures a photographic record portraying nothing but natural movement. Finally it provides automatic connexion between the camera shutter and the study: the insect takes its own pictures.

The device is varied in its details to meet the requirements of the different species brought under investigation, but fundamentally the principle is the same throughout. Thus, the dragon-fly or house-fly is held captive in a small pair of light pincers, which are secured in the closed position by an electro-magnet, but in such a manner as not to inflict the slightest injury. This clamp is placed in the stereoscopic shutter electrical circuit. It is so made that the two legs have a natural tendency to fly apart under the pressure exerted by a spring, but are prevented from so doing by a fixed tooth on one leg engaging with a second tooth mounted on the second leg, a small electro-magnet being placed beneath the outer free end of the rocking arm.

The insect is held gently but firmly in



DRAGON-FLY IN FLIGHT.
Recorded at the rate of 1,500 photos per second.

this clamp which is set up on the side of the bench away from the window. When the electrical circuit is closed the electromagnet pulls down the projecting end of the rocking arm, disengaging its tooth from the fixed tooth on the other leg, and under the pressure of the spring the jaws of the clamp fly apart. The insect being freed at once flies off towards the window, and in so doing sets the camera in motion, because, to reach the window it must traverse the field of the lens, and so be photographically caught in its passage.

The Bee's Flight

For wasps, bees, and similar insects which display the tendency to hesitate before flight, a different device had to be evolved, although this is designed to open the shutter of the camera at the critical moment. This is a tiny glass tube into the rear end of which the bee is thrust head first. It cannot turn round and so is compelled to seek escape from the opposite extremity. But the exit is cut obliquely and covered with an extremely light half-shutter of mica, fitted with a very delicate spring, which actuates the electrical circuit operating the camera shutter. The bee, seeing the partial opening at the opposite end of the tube crawls towards it, this end, of course, being turned towards the window to offer an additional attraction. Reaching the mica shutter the bee endeavours to crawl under it, but in so doing unconsciously lifts the flap and so breaks the circuit. But the camera does not come into action, because the operator manually re-establishes the contact. By this time the bee has emerged from the tube, and has paused to make its final preparations for flight, the mica shutter being partially supported by its body. The bee does not notice the restraint offered by the flap because it is so light and delicate. As the bee springs from the end of the tube the mica flap falls, the electrical circuit is once more broken, the shutter is opened, the camera commences to revolve, and the flight of the bee across the photographic field is obtained.

Many other interesting records of a similar character have been prepared in this manner, the automatic device being adapted to meet the situation to ensure the insect completing the arrangements for setting the apparatus in motion and at its own convenience. Of course, failures are occasionally encountered. The insect, from sheer perversity, will sometimes decline to fly towards the light, or will follow a route to the window which is above or below the field covered by the lens.

Tuning-fork as Time-recorder

There is another feature which deserves mention. The record of an insect's flight would be of little use unless means were introduced to determine the time occupied in the completion of the various phases of movement. This factor is of vital importance to the scientist. As a watch was valueless for the purpose, a more sensitive and delicate time-indicating method had to be evolved. This takes the form of a tuning-fork, making 50 vibrations per second, and operating an electrical signal. The tuning-fork is so set up that the extremities of its vibrating tongues protrude into the optical field, and are thus recorded in every successive image. The vibrations of the fork being known, it is only necessary to determine the time interval, to count the number of photographs taken successively upon the film during a complete single vibration of the fork. In addition, an engraved glass scale is photographed so that the scientist, by perusing this moving picture record, can ascertain the exact distance covered by the flying insect in the fraction of a second.

Obviously, although the photographs are taken at the rate of 2,000 or more per second, it would be useless to attempt to project them at such a speed, because both the beat of the wings and position assumed by the body of the insect would escape discernment by the eye. Accordingly, the

pictures are projected at the normal speed of 14-16 per second by means of the usual apparatus, when the precise flexure and other movements of the wing fabric may be examined and followed. The pictures which Mr. Lucien Bull secured by means of his ingenious apparatus have extended material enlightenment upon many abstruse issues involved in the problem of artificial flight, although, when first produced, they were regarded as being merely a scientific achievement but of little technical significance.

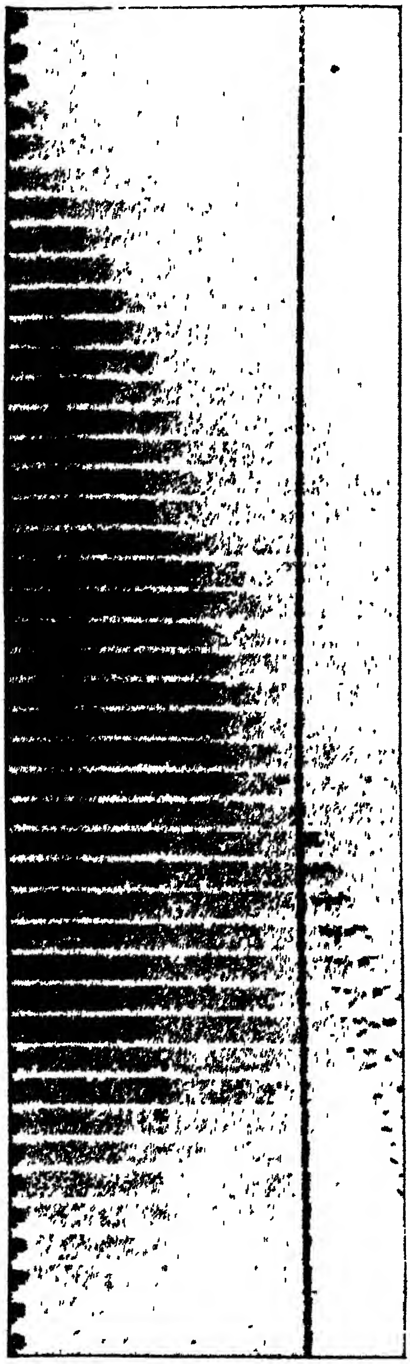
When it was realized that artillery must become the decisive factor in the European war, and it was discovered that our knowledge pertaining to the flight of projectiles was far from being so complete as it ought to have been, the experiments in high-speed kinematography concerning the flight of insects were recalled. As the photographs had been taken at the speed of 2,000 pictures per second, the question arose as to whether this speed could be increased in order to catch projectiles in flight. The French Government approached Mr. Bull for assistance in the prosecution of a series of investigations, relative to the phenomena of ballistics, on behalf of the Allies. The Germans had

CHARGE LEAVING MUZZLE OF SHOT GUN
25,000 pictures per second were taken.

been prosecuting such experiments before the war, but little was known about the results actually achieved with the apparatus which they had contrived.

In this instance, the circumstance that the photographs would have to be taken at a much higher speed necessitated the in stallation . being planned upon a more elaborate scale, and the completion of modifications to satisfy the more exacting conditions. The light produced by the electric spark was intensified and reflected by a concave silvered mirror through a condenser to fall upon the objective, in this instance the projectile. The mirror and condenser were each 16 inches in diameter, and were spaced about 10 feet apart, the trajectory of the missile being about midway between the two. The record upon the film was in the form of crisp sharply defined silhouette. In this instance, the electric motor rotated the camera at 3,000 revolutions per minute, imparting to the film a travelling speed of about 170 feet per second. This permitted 5,000 consecutive images, each $\frac{3}{8}$ inch deep, or 10,000 images $\frac{1}{8}$ inch deep, to be obtained upon the band of film. By virtue of the disposition favoured in regard to the details of the apparatus, it was possible

to set the most delicate mechanism a sufficient distance from the weapon and plotted



REVOLVER BULLET GOING THROUGH A THIN PLANK OF WOOD.

13,000 pictures per second were taken by the "Bull" camera.

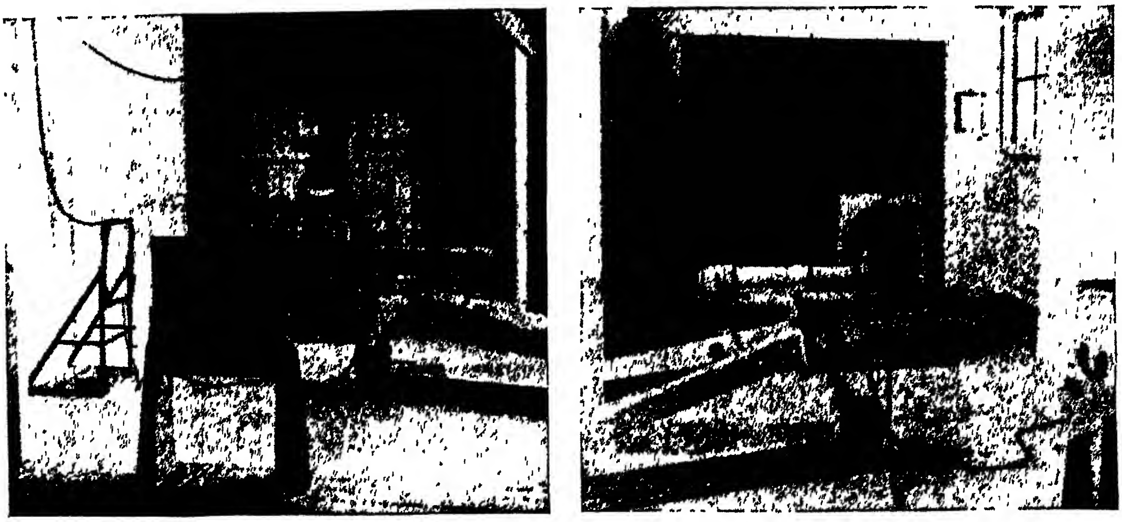
trajectory of the projectile to avoid disturbance or injury from concussion, and without the sacrifice of any essential photographic details.

To obtain the immense number of successive electric sparks per second demanded by the analysis of such an abnormally rapid movement, an electrical arrangement, broadly analogous to the high-frequency system used in wireless telegraphy was adopted, and was found to be highly efficient for this novel purpose, permitting the frequency of the spark to be adjusted with striking precision. One difficulty was experienced. Under extreme rapidity of succession the sparks tended to resolve themselves into a continuous arc, and this was only overcome by concentrating a blast of compressed air, of adequate volume, upon the spark when the frequency exceeded 2,000 to 3,000 sparks per second.

Owing to the velocity of the projectile, and the extremely brief period it required to traverse the photographic field, it was found necessary to render the various details of the apparatus promptly and definitely responsive. The lens had to be fully open at the instant the stream of electric sparks commenced to pour forth. Care had to be observed that the spark discharge did not precede the commencement of recording by more than a fraction of a second. It was similarly imperative that the sparks should be arrested the moment the projectile had passed beyond the photographic field, which coincided with the completion of the revolution of the camera, and to close the shutter the instant this single revolution had been made.

It was also necessary to introduce facilities for the gun to operate the camera so that the projectile might record its own flight kinematographically. This was accomplished in an ingenious manner by pressing the recoil mechanism of the gun into service. A small tube through which a tiny weight was allowed to move freely was mounted upon the gun. At the first movement of the recoil mechanism, this sliding weight established an electrical

circuit which set the camera mechanism in motion and launched the stream of sparks between the electrodes to illuminate the projectile. The apparatus was also thrown out of action by the projectile after it had crossed the photographic field. A wooden frame was set up facing the weapon, in the line of fire, but on the opposite side of the experimental space. Two wire conductors, connected to the electrical circuit, were stretched across this frame, which the projectile struck, thereby rupturing the circuit, extinguishing the rapidly. The gases are promptly followed by the bullet, which is first detected issuing from the muzzle. Clear of the barrel the projectile is almost obscured for a moment by a conical jet of smoke, arising from the combustion of the firing charge, which is now making its escape. The velocity of the smoke falls rapidly, the bullet draws clear, and its flight may now be traced quite easily and clearly. The path of the bullet is intercepted by a thin board of spruce, and in the twenty-seventh picture the bullet is seen entering this obstacle. Upon emerg-



HOW MOVING PICTURES OF A SHELL IN FLIGHT ARE TAKEN

View taken with back to camera. View looking towards Bull camera.

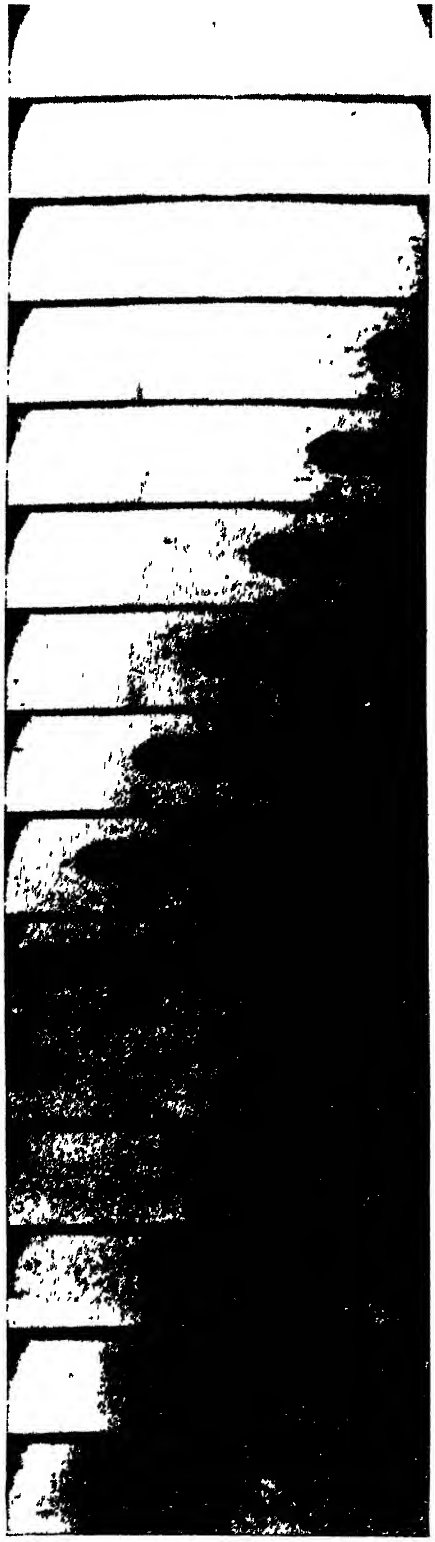
The projectile was fired from a 37 mm. French field-gun.

spark, closing the shutter, and stopping the camera.

Some of the records obtained by this apparatus are of a remarkable character, while many of the pictures were taken at an incredibly high speed. In recording the firing of a 5·65 mm. revolver the exposures were made at the rate of 13,000 per second. In the photograph shown on page 32, the muzzle of the revolver may be seen on the left-hand side. By the time the seventh consecutive picture is reached the gases, which have forced their way through the barrel, become visible. When first seen they are travelling at an enormous velocity, but as the following pictures show, this falls very

ence it is indistinguishable, except as a black mass, because it is entirely surrounded by splinters of wood. In the succeeding pictures the bullet is to be seen drawing away from the splinters, which gradually stream out into an attenuated tail. As the bullet is passing out of the photographic field upon the opposite side, the adhering grains of powder are observed to be gradually disengaging themselves, this action doubtless being accentuated by the passage of the missile through the thin wooden board.

In another film of a similar character, recording the discharge of the bullet from the selfsame weapon, the record was made at



SHELL FIRED FROM 37 MM FRENCH FIELD-GUN KINEMATOGRAPHED 50 CM FROM MUZZLE

The shell is rotating about its long axis. 5 000 exposures per second.

the rate of 15,000 exposures per second. In this instance, in tracing the flight of the bullet, one can follow the disengagement of the wad, and its diminution in speed, as compared with that of the bullet, which draws farther and farther away.

Another series of experiments were confined to the preparation of a film showing the flight of a shell fired from a 37 mm. field-gun under a reduced charge of 22 grammes. These pictures were taken at approximately 5,000 exposures per second, and, in the first instance, there is shown the ring of transparent gases—air doubtless abruptly expelled from the barrel by the discharge. The ring is formed about 28 inches from the muzzle of the weapon and is travelling at a speed of some 24 inches per second. In another record of the flight of the projectile discharged from this gun, the muzzle of the weapon was introduced into the field, thus enabling the missile to be caught kinematographically when moving at its maximum velocity. The success of these films prompted the acceleration of the apparatus, and one record was secured in which the photographs were taken at the incredible velocity of 25 000 a second. (See page 31.)

While the subjects are far too technical to attract the interest of the ordinary picture-palace patron, the achievements of Mr. Bull and his staff have been adopted, with modifications, by industry. It is appreciated in this province because it extends to the laboratory staff and apprentices the opportunity to reduce upon the screen mechanical movements, too rapid to be followed by the human eye under normal or actual working conditions, to a pace permitting easy or leisurely study and without any sacrifice of actuality. It has also been found possible to prepare high-speed films capable of making popular appeal, as, for instance, of athletes, which, when projected upon the screen at normal speed, reveal unsuspected actions, because they were too rapid to be detected by the eye.

INCREASING THE OUTPUT FROM THE MINE

The "Jeffrey" electric entry-driver being warped into position by wire rope and jack to bear against the coal-seam The canvas ventilating duct is seen on the ground at left.

Mining Coal without the Miner

AN ELECTRICALLY OPERATED MACHINE WHICH REVOLUTIONIZES ONE OF OUR OLDEST INDUSTRIES

ALTHOUGH electricity is seriously disputing the supremacy of steam, and water-power is striving to usurp coal from its premier position as the primary medium for the generation of energy, it must not be imagined that the era of the solid mineral fuel is drawing to a close; far from it. Coal has become an indispensable attribute to industry, and scientific research is being pursued so energetically that the coming of the day is indicated when coal will not be regarded as a fuel, but as a staple, comparable with cotton, wool, and other materials, for the manufacture of a host of products, including alcohol. When science has completed its investigation the only constituents of the coal which are likely to be regarded as fit for fuel will be the gaseous residues, hydrogen and methane or marsh-gas, resulting from the distillation of the raw material, that is, always presupposing that science has not discovered, in the meantime, some more profitable application for these two seemingly waste products.

Consequently the mining of coal will be

carried on as vigorously as ever. But the indications are that this tedious and hazardous operation will become less and less dependent upon the expenditure of physical human and animal effort than has been the case hitherto. The task of the miner at present is by no means envious; and in this mechanical age we witness the expenditure of diligénce and fertility of thought in the endeavour to eliminate the man from this occupation. This prompts the question as to whether the miner, as we know him to-day, will be as effectively superseded as the worker in many another task by the perfection of wondrous mechanism. Developments certainly appear to be pointing to such an eventuality; progress in this field is being recorded much more rapidly than may, perhaps, be imagined.

Among the wonderful devices which have been evolved to this end is the machine which has been contrived by a persistent inventor, Mr. E. C. Morgan. It is technically described as an "entry-driver," but it may be more popularly called a machine which cuts, breaks down and loads the coal into the trucks with the minimum of human attention or assistance. The practicability of consummating such an end has been the dream of inventors specializing in the "mechanization" of the coal-mine for many years past, and many striking expressions of ingenuity in this field have been elaborated and subjected to test; but until the appliance contrived by Mr. Morgan appeared, complete success had not been attained.

The "Entry-driver"

About six years ago the inventor in question completed his final designs, which he submitted to the Jeffrey Manufacturing Company, of Columbus, Ohio, specialists in everything that pertains to the mining of coal. The appliance was subjected successfully to trials, and this company at once decided to introduce it to the mining world. In view of the failures that had attended such attempts to displace the miner, it proved to be no easy matter to persuade the mining companies that success had at last been recorded.

Shortage of labour actually compelled the American colliery interests to investigate the claims of the new entry-driver. Impressed by what they saw when the machine was subjected to trial, and recognizing the volume of labour, time and money which it could save, certain mines decided to submit it to practical trial in their workings. The fields of Virginia were the most enterprising in this respect, and the success attained by the installation of this machine created a decided sensation. All apprehensions as to the appliance not being able to stand up to its arduous work have been completely dissipated. The machines which were installed in the mines four years ago are still working as efficiently as ever. Their output, and also their dependability and durability, are leading to striking developments in this direction.

The Electric Motor

The machine is one of the most ponderous units ever introduced into the coal-mine. Incidentally, its introduction has been rendered possible essentially because of the perfection of the electric motor. The simplicity, facility, and delicacy of electric control enable any and every moving part of the machine to be brought to bear upon its appointed task with the minimum of skilled attention.

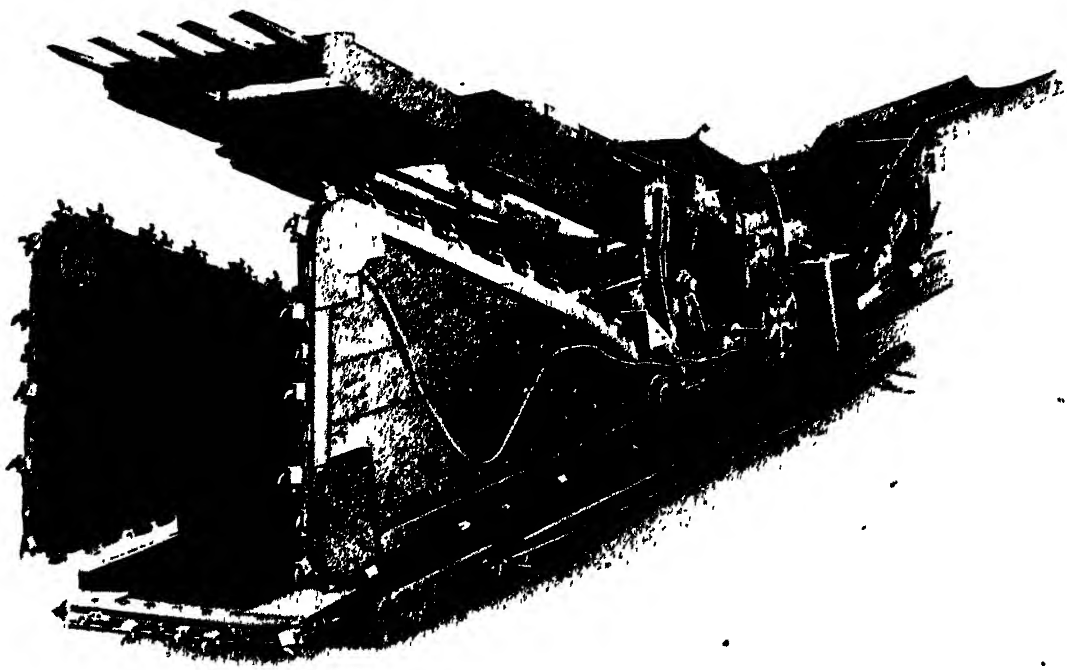
The entry-driver comprises a massive steel frame and wings or shears. The foundation frame or pan carries a second frame which is furnished with an endless cutting-chain, and as it is in constant movement, undercutting of the seam is continuous. Each side or shearing-frame of triangular shape, and set vertically, is similarly fitted with an endless cutting-chain. Consequently, when the machine is pushed against the coal-face, a threefold cut is made into the seam simultaneously, the cut being along the bottom

How the Entry-driver Works

and from the corners of the latter upwards in two vertical lines. No top cut is made.

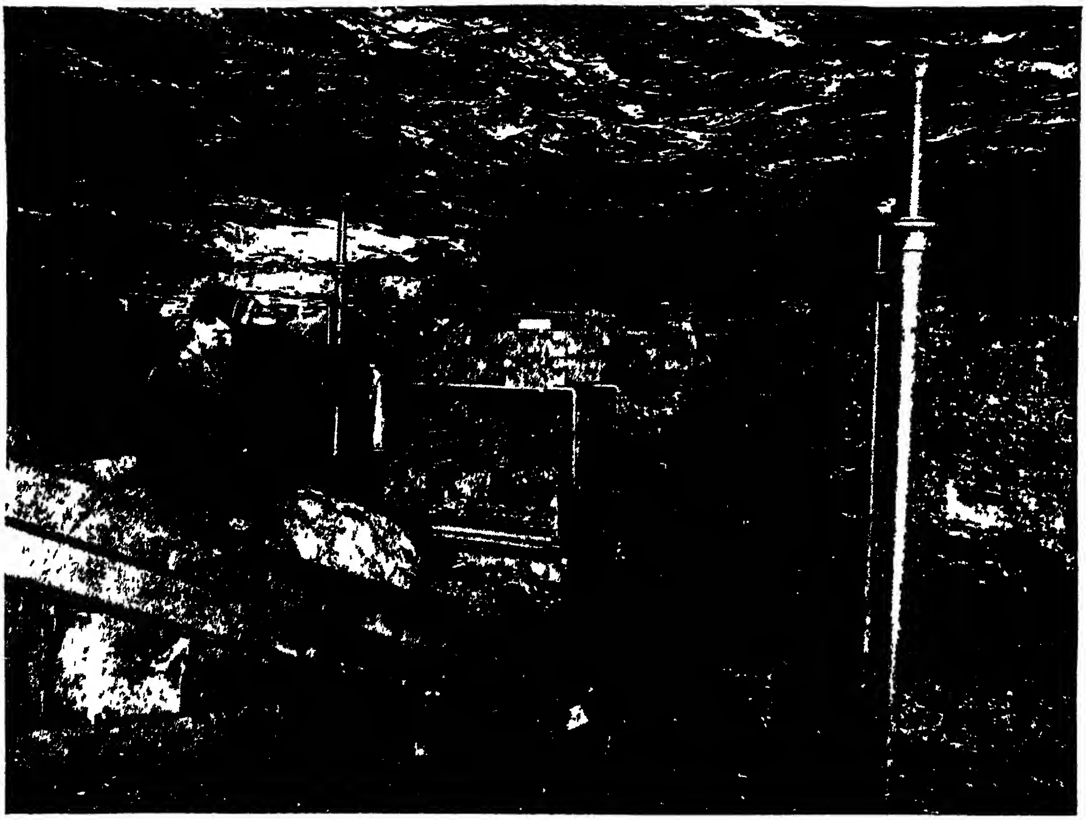
While the bottom and side chain-cutters are sawing their way into the wall it is necessary to bring down the coal within the three-sided cut which is described. This is accomplished by means of the second noteworthy feature of the machine. To the rear end of the foundation frame is pivoted a massive rectangular jib-like structure which can be moved within certain limits through a vertical arc. This is the ram, and as it is narrower than the space between the shear-frames, it can be manipulated between the latter. This ram is extremely powerful, and the most prominent characteristic is the array of five equidistantly spaced large chisels projecting like teeth from its front cross-beam. The ram can be set at any height within the limits of working by the simple movement of a lever, and, the desired elevation attained, it is maintained until the cut has been completed.

The operator, after the machine has been warped into position against the coal-face, and when all is ready to set the chain-cutters in action to saw into the seam, sets the ram at the height favourable to working. The power is switched on. The cutters commence to hew their way into the coal, and in the course of a few minutes by which time the cuts have been carried to a certain depth, the chisels of the ram come against the face to crunch their way into the wall, breaking down the mineral within the cut.



THE ELECTRIC MECHANICAL ENTRY-DRIVER.
Both the undercutting and the side shearing-frames are fitted with endless cutting-chains. The ram carries five chisels, and can be adjusted to any height by a lever. The machine makes a 7-foot cut in a vein 6 feet in height.

The coal thus displaced tumbles upon the conveyer set in the undercutting frame to be carried away from the working-face to the rear of the machine, when it is transferred to a second conveyer extending from the rear of the appliance to a point some distance away. It is then discharged



THE ENTRY-DRIVER PENETRATING A WALL WITH THE RAM BREAKING DOWN COAL.
The coal is moved to the rear by a conveyer for transference to a second conveyer, and thence to the waiting cars, without being touched by hand

either direct into the tramway cars or a hopper. This rear conveyer is mounted upon a turn-table in such a manner as to be swung in any position independently of the entry-driver and the string of waiting cars. That is to say, it is not necessarily compelled to assume the longitudinal axis of the machine proper. This is a distinct advantage, inasmuch as the driver may make the first cut through coal but then be called upon to head through slate or gob. The latter, after being broken down, naturally fails upon the conveyer of the entry-driver, and thereby is led to the rear and discharged upon the second conveyer. The last-named, having discharged its load of coal from the first cut and now receiving the useless gob, is swung round to dump the waste to one side or into other cars for removal. In this way mixture of useful coal and useless slate is avoided.

The operation of the machine is simple. When set against the coal-face the cutting frame is drawn back as far as possible into its foundation pan. This is done by means of wire ropes wound over a sheave mounted upon the driver and electrically driven. The pan is warped to the desired position against the seam, the necessary alignment being effected by the manipulation of the wire ropes. Once the pan has been set in position, its weight is sufficient to keep it there and to resist any back-pressure which may be induced from the coal-face.

The machine shown in the accompanying illustrations will work upon a vein 6 feet in height, but the shearing-frame can be made to meet any condition in this respect; it is only necessary to leave a clearance of about 6 inches between the top of the shears and the roof to obviate

the latter being fouled by the shear-frame cutting-chains when handling the driver. The machine in question will make a 7-foot cut in a vein 6 feet in height; that is to say, the cutting-chains will penetrate the face of the seam to that depth.

The requisite preparations having been completed the machine is set in motion, the three distinct and separately operating chains sawing individually into the wall. The forward feed of the machine in its pan is steadily maintained by means of the steel rope. When the chisels of the ram exercise their disintegrating force the coal comes tumbling down in a steady stream, being dislodged for the most part in large masses, which are removed by the conveyer to the trucks behind.

But the coal may be tough, and fail to break down under the force exerted by the ram after being cut or sheared on both sides and at the bottom. In this event one or more hydraulic jacks are fitted in one of the shearing-frames. When the machine has driven its way into the face for a certain depth, say 20 to 30 inches, according to the character of the coal, water is pumped into these jacks. A tremendous pressure is instantly set up and this splits and cracks the coal in all directions, thus facilitating the effort of the ram to bring it down. Such treatment usually results in the coal being detached in huge lumps, possibly larger than are forthcoming from the direct use of the ram. It may be stated that "jacking," in this manner, is probably the most prompt method of coping with the situation, since only about 15 seconds are required to bring this persuasive force into play.

When the machine has been driven to the full depth, it is pulled back into its pan

TRANSPORTING COAL FROM THE SEAM-FACE

The coal being discharged from the conveyer into hoppers. Three men are sufficient to operate the machine, which brings down 7¼ tons of coal with each cut.

to the normal position by means of the rope. This is a simple operation occupying about one minute. Withdrawal reveals a huge cavity 5 feet wide by 6 feet high, and 6 feet deep in the working face, from which the coal has been excavated. Although the working depth of the machine is 7 feet, as a rule only a 6-foot cut is obtained. This cavity represents 180 cubic feet of coal, or about $7\frac{1}{4}$ tons, and this quantity, by the aid of the electrically-operated driver, is mined and transferred to the trucks in 20 minutes!

The First or "Sumping Cut"

When the first cut, generally known as the "sumping cut," has been made, the rope controlling the feed and withdrawal of the driver is hooked over a sheave on the forward side of the machine and secured to a jack at the face of the opposite rib. The motor is again set in motion, and in this way the machine is pulled bodily sideways the width of the cut, and realigned for its succeeding attack upon the seam, these preparations requiring no more than three minutes. The second cut, next to the first, is now made. In this instance, however, the shear on one side will feed forward in the previous cut whence the coal has been taken out. Consequently as no actual cutting operation is required on this side, the corresponding shear is thrown out of action, and the chain drive is declutched, so that the shear runs in idly. The previous cycle of operations is repeated, only in this case, the cut being known as "open," the task is completed in about 15 minutes.

Owing to the advisability of a clearance between the top of the shears and the roof, a "lintel" of some 6 inches of coal is left in the cut, but this is afterwards broken down by hand, and the roof finished off cleanly and squarely by means of the ram. Similarly, the machine leaves a small ridge —the depth of the pan—at the bottom of the cut, but this is no more than that attending the use of the breast machine. However, the bottom of the first cut is cleaned up and levelled by hand while the machine is making the second cut. By the time the latter has been completed, the area of the first cut has been cleared, and the machine can be warped over and brought to bear against a fresh section on this side continuing the line of the first cut in the coal-face. While this cut is being made the helper cleans up the floor of the previous cut, and so on, following the machine from cut to cut to and fro across the seam as the advance is made.

Explosives Rendered Unnecessary

The advantages of this device will be obvious. In the first place explosives are rendered totally unnecessary, and the ability to dispense with these disintegrating agents not only eliminates all possibility of damage being inflicted upon the roof, but renders mining safer, and, at the same time, does not vitiate the atmosphere at the working-face of the mine with foul gases.

The time- and labour-saving characteristics of the driver are equally pronounced. If a hopper be employed to receive the coal from the conveyer, as is recommended, work can be carried on continuously. If the storage hopper be omitted, and discharge direct into the tram-cars be employed, the machine must be stopped when a car has been filled to allow an empty vehicle to be brought into the loading position. Practical experience has proved that such transference of cars takes about five minutes, and, as a truck is charged within a few minutes, the delay is likely to be frequent, and in the course of the day's work to represent an appreciable period of lost time. When the storage hopper is being used the man operating the machine, the "runner," ignores the loading of the cars; the hopper is taking care of this factor. Delivery of coal into the hopper is interrupted only when the machine is being moved from one cut to another, but the hopper has sufficient coal to continue

truck-loading without interruption during this process. Consequently, the delivery of coal into the cars for removal to the surface is continuous.

Only three men are required to control the entry-driver. One man attends to the machine, supervising all direct operations, and his task is not exacting, seeing that all movements are electrically actuated. He is attended by a helper who does what timbering is necessary, looks after and cleans the top and bottom of the cut, and assists in warping the driver from cut to cut. A third man is necessary to attend to the hopper and to trim the cars. Thus, under steadily working conditions, the machine will easily mine and load 16 tons of coal per hour with the aid of three men. Under normal conditions this machine will drive entries from four to six times as rapidly as is possible by familiar methods. Moreover, it is equally adaptable for chamber work. The circumstance that explosives are rendered unnecessary, while roof damage is reduced to the minimum, entails less resort to timbering, the saving under which heading alone is likely to prove considerable. However, it can be employed with equal success under conditions where the roof is poor and somewhat elaborate timbering is made imperative.

THE PORTABLE ELECTRIC LOADING CONVEYER.
Loading coal into cars. On the track is the trolley for moving the loader from point to point, it is self-propelling.

Control of this machine is of the simplest character. The entry-driver is equipped with a 70 horse-power electric motor, wherewith all operations are carried out by the aid of simple and suitable controllers. The machine is fitted with electric head-lamps which adequately illuminate the face upon which it is working, while other parts of it are also well lighted by means of attached incandescent electric

lamps having sufficiently long flexible cable connexions to permit their movement to, and attachment at, any point desired.

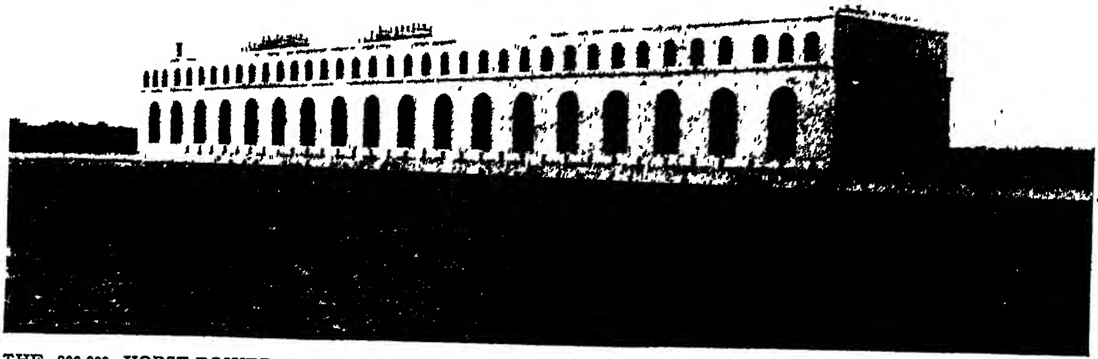
By the aid of machines of this character it is possible to expedite the development of a new mine. So soon as the overhead equipment, shaft or working of the property is ready, the machine can be installed—a battery of entry-drivers if the conditions so permit—and the desired output attained within a short time, especially if continuous operation through successive shifts, as is recommended, be observed. Then again, work can be concentrated and the yield derived from a small area. Under this concentration system experience has shown that cost does not increase as the mine is being worked out, for the simple reason that the workings are always confined to a small territory. The only factor which is affected is the main haulage, which, obviously, becomes longer, but this does not affect the cost to any material degree. The entry-driver makes no demand upon special or highly skilled labour. It has been found that proficient short-wall machine runners are eminently adapted to its control and operation. Although three men may be accepted as constituting an adequate working gang under normal conditions, an extra man may be required if the slate be found heavy.

FRESH AIR FOR THE WORKING-FACE.
An 8-inch electric fan-blower delivering 500 to 600 cubic feet of air per minute through an 8-inch canvas pipe laid upon the ground.

The operations of the entry-driver may be appreciably improved by the acceptance of two auxiliaries. The one is a coal-loading machine; the other a simple but highly efficient ventilating system. The loading machine may be compared with the rear conveyer of the entry-driver. It is not designed to displace the latter, but to be used in a supplementary capacity, especially where additional man-power may be indispensable. It has been designed essentially to accelerate loading capacity with the minimum of physical effort.

The loader, driven by a small electric motor, is a self-contained and self-propelling portable appliance. It is mounted on a small trolley whereby it can be moved over the mine tracks to the working position, and can be left on the truck, or if preferred, moved from the latter and installed at a more convenient point. Its mobility is secured by the provision of a grooved rail along which it travels to the situation desired, an operation easily within the capacity of one man. The coal is worked on to the lower end of the loader which is flush with the ground, and lifted mechanically to be dumped into the truck.

The ventilation of the entry in which the driver is at work has a far-reaching effect upon output, and, to meet the special conditions which have arisen, a simple attribute has been devised. The arrangement comprises an 8-inch blower fan directly coupled to a small electric motor and delivering 500 to 600 cubic feet of air per minute through an 8-inch canvas pipe, which adapts itself to the inequalities of the road surface.



THE 200,000 HORSE POWER HYDRO ELECTRIC POWER HOUSE OF THE MISSISSIPPI RIVER POWER CO. AT KEOKUK.

The structure for the 110,000-volt transmission line can be seen on the roof.

Triumphs of Transmission—I

HOW CURRENT IS LED OVER ENORMOUS DISTANCES

WHEN an ingenious enterprising Frenchman, Marcel Duprez, succeeded in transmitting electric energy to the extent of 3 horse-power over a distance of 24 miles, employing ordinary telegraph wires for his purpose, intense excitement was provoked. A new era was inaugurated in the world of power. Those of brilliant, if popular, fertility of thought at once raised the argument that if it were possible to transmit power in this manner over a distance of 24 miles, why should it not be equally feasible to distribute thousands of horse-power at points 100 or even 200 miles from the centre at which the energy was generated?

The commercial possibilities of electric transmission were first indicated by Dr. William Siemens in 1877, but the first decided attempt to grapple with this question was made by the Westinghouse Electric International Company, of Pittsburg, Pa., about thirty years ago. A generating station was built in San Antonio Canyon, Southern California, to supply single-phase alternating current at a pressure of 10,000 volts for lighting the towns of Pomona and San Bernardino, 14 and 28 miles away respectively. The current was generated at 1,000 volts, and was stepped-up to the 10,000 volts by means of forty 6-kilowatt transformers, which were the largest units of this type constructed up to that time.

After the line had been opened the constructional engineers decided to carry out a series of experiments in the transmission of high-tension current in order to gather some reliable data concerning the losses likely to be encountered, and the most economical pressure, upon which points there was very little conclusive knowledge. The experimental line was about 60 feet in length and comprised nine parallel wires placed horizontally, and spaced about 4 inches apart. It was erected in a

convenient building, and the wires were carried upon insulators mounted upon wood. The frequency of the current used varied from 60 to 135 periods per second, while the pressure ranged from 20,000 to 50,000 volts. The losses were found to be slight up to 20,000 volts, but increased rapidly as the pressure was raised from 20,000 to 36,000 volts. It was also observed that as the 20,000-volt limit was passed, the wires commenced to grow luminous and to hiss, while the building became charged with ozone.

The experiments were repeated in 1895 across a line $2\frac{1}{2}$ miles in length running from the central generating station at Ames to the Gold King Mill, Colorado. It was of iron wire 0·156 inch diameter mounted upon glass and porcelain insulators, various shapes and sizes of which were tested. At the mill a 100 horse-power synchronous motor was installed and used in conjunction with the investigations, the energy being transmitted at pressures ranging from 25,000 to 33,000 volts. In the January of the following year the trials were resumed and, upon this occasion, the pressure was increased to 45,000 volts, while three months later it was lifted to 50,000 volts. When the pressure of 50,000 volts was applied the wires were plainly luminous at night, while the hissing characteristic of high-tension currents could be heard at a distance of several hundred yards.

A Synchronous Motor of 100 horse-power

The results of the Westinghouse experiments served to stimulate interest in the transmission of electricity over longer distances and at higher pressures than had ever been contemplated up to this time. One of the first transmissions of this character to be installed—which was in connexion with one of the earliest water-power generating plants to be completed—was at Provo, in the State of Utah, where the Telluride Transmission Company supplied current to the Gold King Mine across a line $33\frac{1}{2}$ miles in length.

Longer Distances at Higher Pressures

This was regarded as a somewhat daring stride, but compare it with the transmission accomplishment of the huge power-station built at Keokuk, which compels the turbulent Mississippi River to pay tribute to industry. This distribution system comprises one main line carrying current at the pressure of 110,000 volts for a distance of 144 miles to St. Louis, and three other lines operating at 11,000, 33,000, and 66,000 volts respectively. But the 11,000- and 110,000-volt lines are accepted as representing the two extremes, and accordingly extend the convincing basis of difference in construction of the two lines.

The line at 11,000 volts—this is the potential at which the current leaves the generator—runs from the power-house to Burlington, 40 miles to the north, feeding the distribution network pivoted thereon. Keokuk is on the Iowa bank of the river, while the town of Hamilton is upon the immediately opposite shore. Lead-covered cables carry the current across the dam to Hamilton and across the locks and dry docks to Keokuk, where a small house has been erected for the reception of the cable, whence the current is passed on to the main substation to be stepped-down by a 1,000-kilowatt bank of transformers to 2,200 volts for distribution throughout the city and environs. The service includes supply to the tramways and for public electric lighting. From this sub-station a single 11,000-volt line is carried for a distance of 5 miles to a company engaged in the manufacture of explosives.

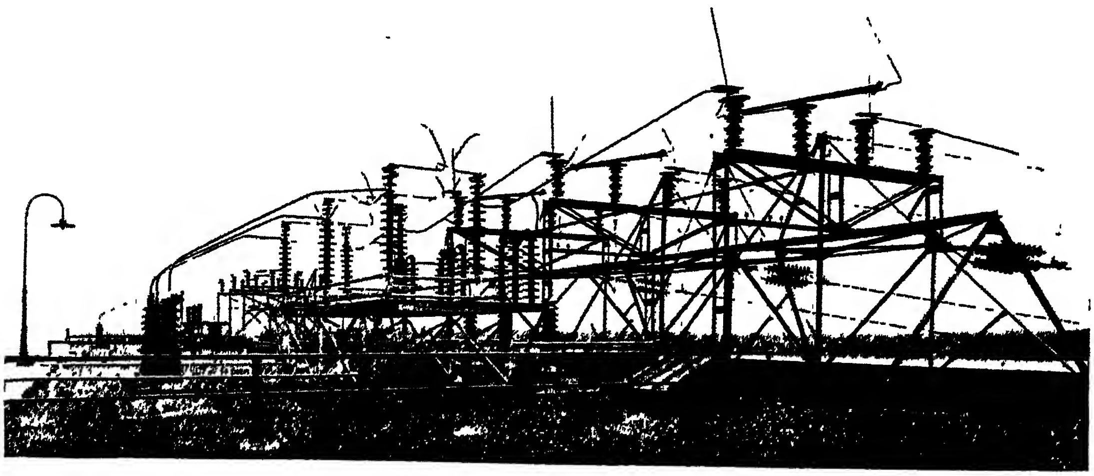
The Keokuk-Hamilton Station

The supply cable to Hamilton is led into the local sub-station, where it is stepped-down to 2,200 volts for local supply. From this station two overhead circuits, carried on single poles, extend northward, following the river to Fort Madison, where

the line is tapped to satisfy power requirements in the vicinity. Then the lines cross the waterway, to be led into Burlington station, whence radiate 11,000-volt feeder lines to local bulk consumers. A spur of the 11,000-volt line is continued a few miles down the river to allow the town of Warsaw to be brought into the scheme.

The 110,000-volt line is of a vastly different character. Upon the roof of the power-house is an imposing structure whence the current is brought from the high-tension switch-gear to be launched upon its long overland journey. The first step is one of considerable magnitude, representing as it does a single leap of 2,800 feet across the waterway. This span is supported at the Illinois shore end by two lofty steel towers from which the line extends continuously to St. Louis. The total length of this transmission is 144 miles, and it has been set out in as straight a line as the engineer could obtain. Although several angles were found to be unavoidable, the line is only 14 miles longer than as the crow flies, while it is more than 30 miles shorter than the railway connecting the two points.

For its accommodation the company had to secure a right of way 100 feet in width, representing 1,320 acres of farming land, which were purchased from 451 different owners. From one end to the other of this narrow swathe a wagon road has been built to allow any and every part of the line to be reached easily and promptly. For the greater part of its length the transmission runs through the State of Illinois. Owing to the meandering of the waterway a crossing had to be made at one point, the line being slung between lofty steel towers similar to those at Keokuk, while it was also found necessary to span the Missouri River in a similar manner, the southern terminal being at Florissant, on the confines of St. Louis. The route passes Hulls and Meppen, which have become important "divisional" points, inasmuch as from these two places spring the 33,000- and 66,000-volt lines already mentioned.



THE KEOKUK POWER-HOUSE TERMINAL OF THE 110,000-VOLT LINE RUNNING 144 MILES TO ST. LOUIS.

The line comprises 6 main cables, each ⅝-inch diameter, composed of 19 twisted copper wires, making a strand nearly 20,000 miles in length. Its first leap is across the Mississippi River in a single sweep of 2,800 feet.

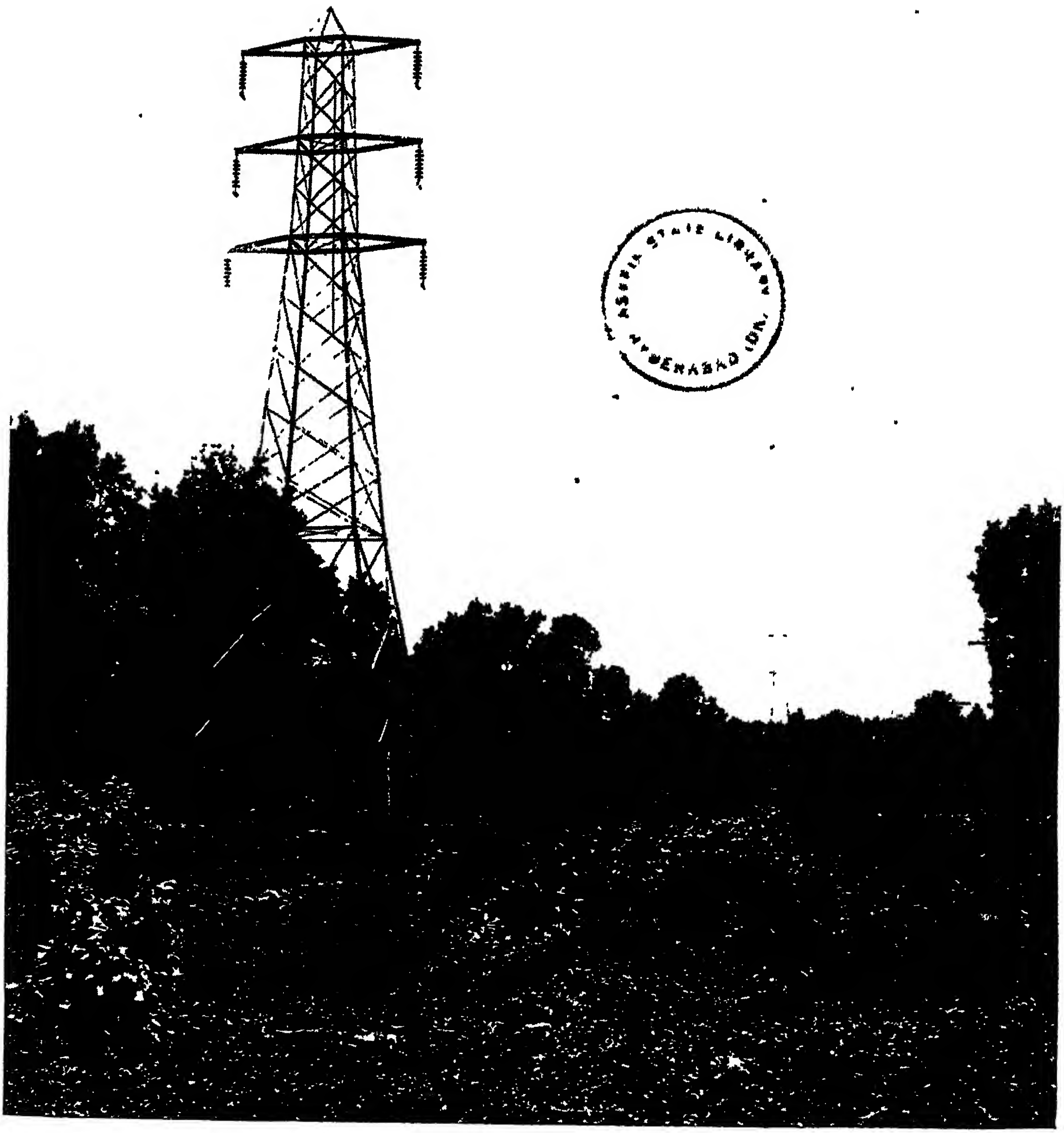
The Keokuk–St. Louis transmission comprises 6 main cables and a guard wire over them. Each cable is ⅝-inch diameter, composed of 19 twisted wires of copper. The total length of the strand is nearly 20,000 miles. Down the centre of the 144 miles of right of way extend in

a continuous row 1,062 steel towers, each 80 feet in height, and spaced 800 feet apart. They are of massive construction, supported on heavy concrete foundations, the country traversed being exposed to violent storms. The standard type of tower weighs fully 6,640 lb., but at short intervals anchor towers, exceeding 10,000 lb. in weight, are introduced. The total weight of steel worked into these towers exceeds 9,000,000 lb.—4,000 tons. So strong is their construction that they will r sist the force of the most violent tempest ever likely to occur in this part of the country—an essential condition when the volume of industry dependent upon this source of power supply is borne in mind.

The standard tower carries three cross-arms, from the extremities of which depend the insulators. The cables are thus suspended instead of being carried upon pin insulators fixed rigidly to the cross-arm, and project vertically, as in the case of the familiar telephone and telegraph wires. At the anchor towers a different system is followed. To each extremity of the cross-arm two insulators are fixed, one being extended on each side, to which the cable is secured. In this arrangement the insulators resemble outstretched arms in the direction of the line. The current does not pass through the wires round the insulators as in the usual way, but through a loop extending from the outer extremity of one insulator to the end of its fellow, and in this way is led past the towers.

ONE OF THE HIGH-TENSION ROOMS AT THE KEOKUK POWER-HOUSE.
The current, stepped-up from 11,000 to 110,000 volts, is led to the structure on the roof of the building for its long overland journey.

The anchor tower and the system of supporting the lines give enhanced stability. In the construction of the line approximately 11,000 insulators, involving 90,000 disks of porcelain, were used. All the cables have been subjected to many



A GLIMPSE ALONG THE MAIN KEOKUK—ST. LOUIS 110,000-VOLT LINE.

The line is only 14 miles longer than as the crow flies. There are 1,062 steel towers of the standard type. Each weighs 6,640 lb., is 80 feet high, and stands 800 feet from its neighbour in a right of way 100 feet wide. The six power cables are supported by suspension insulators.

times the strain which they will ever be called upon to bear, and the line has sufficient capacity to take care of the current which must pass over it, even if one-half of the cables should happen to collapse simultaneously. The insulators have also been subjected to severe trials to circumvent leakage, the test being 440,000 volts dry and 300,000 volts in the rain. At the St. Louis end of the transmission a large sub-station has been built, where the high tension is broken down to the workable voltage demanded in the city and neighbourhood, an intricate network being fed in this manner.

POWER SUPPLY ZONE OF THE KEOKUK HYDRO-ELECTRIC STATION UPON THE MISSISSIPPI RIVER

The circle has a radius of about 160 miles.

As previously explained, the 33,000- and 66,000-volt lines are really offshoots from the main transmission circuit. The first is taken off at Hulls, which is about 50 miles south of Keokuk. This sub-station accommodates three 4,000-kilo-volt-ampere transformers, with necessary switching equipment for drawing off the supply from the high-powered line and breaking it down to 33,000 volts, at which it is fed into the two subsidiary branch lines running to Quincy and Ilasco respectively. The first-named—No. 2 copper wire strung on wooden poles—runs for a short distance along the St. Louis right of way parallel to the main line, and then strikes off through a separate right of way and the city streets of Quincy to the plant of the local gas, electric, and heating company. The total length of the line is 18 miles. Here a step-down station of 4,500 K.V.A. capacity breaks the pressure down to 6,600 volts, at which potential it is delivered to the local undertaking.

The Ilasco line is similar in all essential respects to the Quincy branch, except that it has to swing across the Mississippi. As it is quite possible that these supports may be called upon at a subsequent date to carry a line of 110,000 volts, the river-crossing towers are of the standard pattern used upon the St. Louis transmission. Moreover, this second branch runs over a private right of way for its entire length, the current being required for the operation of a large cement works at the terminal. The Mississippi River Power Company has built a step-down 9,000-K.V.A. station to deliver energy to the mills at the required pressure, namely, 2,200 volts. These works have been completely converted to electrical operation, the motors ranging from 400 to 1,900 horse-power for the running of the various machines.

At Meppen, 110 miles south of Keokuk, the trunk 110,000-volt transmission is once more tapped, and the pressure reduced in the sub-station to 66,000 volts, at which it is fed on to the Alton line. This is also of No. 2 copper, supported by suspension insulators, similar to those employed on the trunk transmission, but having only

four instead of seven disks. The insulators are hung from H wooden towers spaced 300 feet apart, and having two overhead ground wires, one placed at the top of each pole. This line, 26 miles in length, traverses rolling country and crosses the Illinois River with four 1,200–1,800-feet spans supported by standard steel towers. The current is delivered at Alton to the East St. Louis Light and Power Company at line pressure for transmission to East St. Louis. The Mississippi River Power Company has installed all the requisite plant in the sub-station of the purchasing company, the equipment including two 1,500-K.V.A. synchronous condensers. These are exactly the same as alternating-current generators, but are run as motors under no load, their purpose being merely to assist in maintaining the voltage at Alton and St. Louis constant and satisfactory.

A special telephone line has been built along the St. Louis right of way, but, owing to the high voltage of the power-line, has been strung on separate poles. This links up with the power-house telephone system, and thus brings the chief dispatcher into direct touch with every yard of the transmission. At intervals of 4 miles a telephone call station is provided where the "trouble men" can establish conversation with the generating station.

The Maintenance of the Line

For the maintenance of the line a small army of men and an elaborate organization are essential. Spaced at intervals of about 20 miles along the "lines" are houses for patrolmen, watchmen and repairers. By the aid of the telephone these "trouble men" can communicate with one another. Furthermore, at convenient points, boxes are provided complete with tools and supplies for the conduct of repairs. In such an undertaking as this the guiding principle is to detect any possible weakness and to remedy it before it can assert itself and thus possibly interfere with the service. The line has to be inspected periodically in precisely the same manner as a railway track is examined regularly by the gangers.

The "Trouble Man"

Each patrolman is responsible for his section of the line and must be ready to co-operate in time of an emergency with his comrades on either hand. During his round of inspection the patrolman is compelled to report to the chief dispatcher, at least three times a day, the condition of the line in his section and to receive any orders that may be awaiting him, such as the investigation of some fault which may have manifested itself unknown to the "trouble man." It is only by the observance of strict routine and a comprehensive system such as this that the confidence of the public in long distance transmission can be obtained—confidence which asserts itself in the accretion of additional customers, and the exploitation of the capacity of the generating station to the 100 per cent. limit.

What Transmission Means

Some idea of what transmission means to a highly organized undertaking, wherein several high-powered generating stations are linked together to form a homogeneous whole, is afforded by the Montana Power Company. As this undertaking operates 13 hydro-electric stations having a total producing capacity of 217,450 kilowatts, and supplies over 1,100,000,000 kilowatt-hours per year to more than 70 cities, towns and villages in addition to large individual consumers, it is obvious that an extensive and highly developed transmission system must be maintained. This fact becomes emphasized when it is stated that the area of supply stretches 300 miles from north to south by 260 miles east to west. A district of 78,000 square miles, in such a State as Montana, where the country is extremely broken, and where the hostile forces of Nature are particularly formidable, is not readily or cheaply gridironed with an aerial network. The 2,000 miles of high-tension through

lines which have been built, together with the requisite sub-stations to step-down the power of the current, have involved an expenditure exceeding £2,000,000 hives absorb more than 18,000,000 kilowatt-hours apiece during the course of the year, which is equivalent to the whole of the current taken by the 38,000 private con-

A HYDRO-ELECTRIC ENGINEERING TRIUMPH IN CUTTING OUT DISTANCE

The Montana Power Co.'s "Express" line from Rainbow Falls to Butte, in the course of its 130-miles' run, climbs to a height of 8,200 feet, and leaps the Missouri ravine in a single span of 3,034 feet. Even in the clearest weather the opposite towers appear spidery in outline.

The foremost consuming centres of supply are Butte and Anaconda, which constitute the heart of Montana's staple industry—the mining and smelting of copper. Some of the customers in these two pulsating sumers distributed through the supply area. In order to ensure adequate current for the copper industries, four lines, each transmitting current at a pressure of 110,000 volts, and following four

different routes, extend from the large generating station at Great Falls to the two towns in question, a distance of about 150 miles. Then the customers within a radius of the Great Falls have also to be similarly served, and for their convenience there are numerous lines, carried on wooden poles, operating at 50,000 volts.

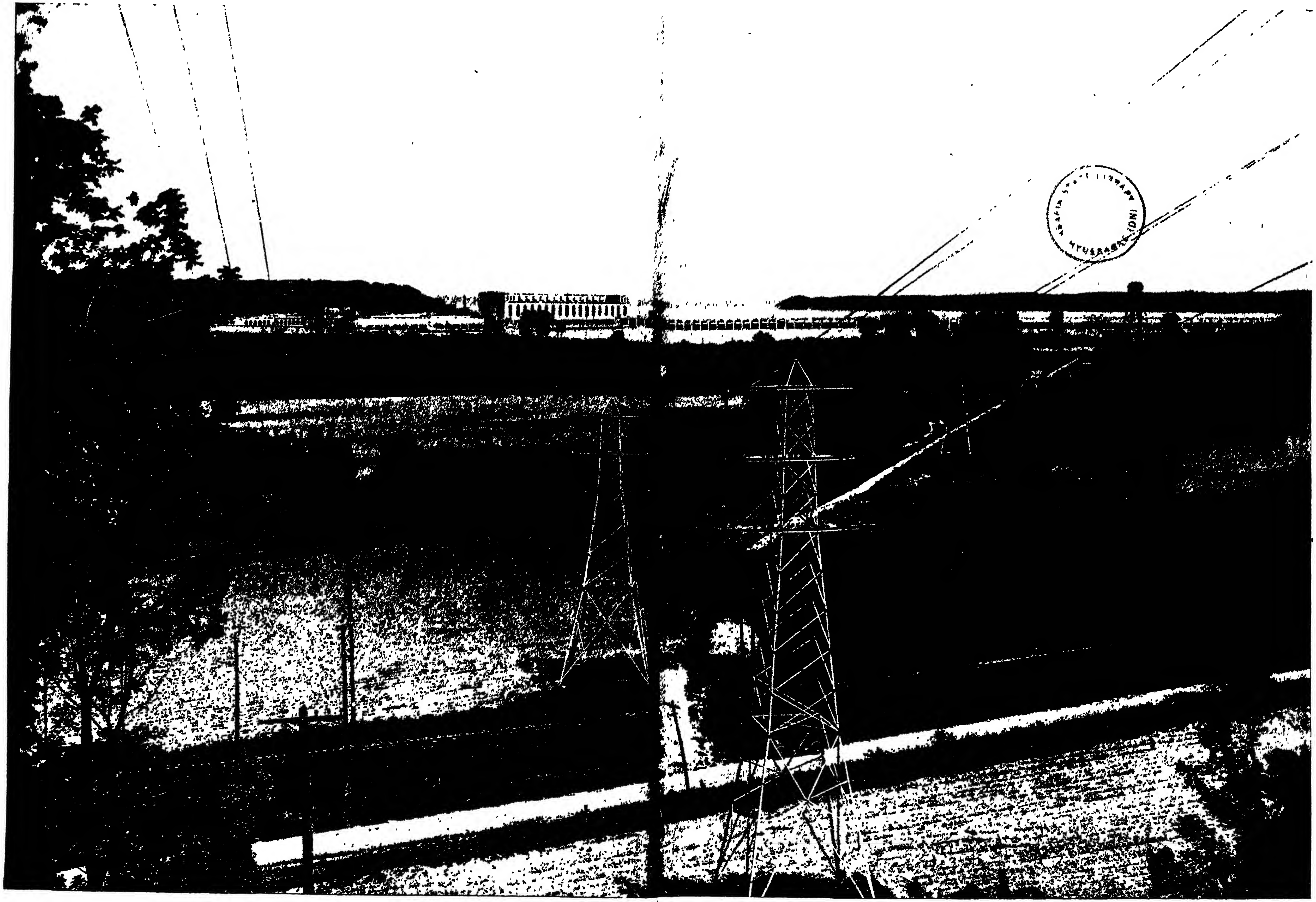
The two plants at Canyon Ferry and Hauser Lake respectively are tied into the general high-tension system, and the power generated at these stations is transformed up to 66,000 volts. The first-named also furnishes power to Helena at 11,000 volts over a line 13 miles in length. Butte is also enabled to draw power from the Madison River plants, the potential of the express line being 110,000 volts. But the two stations in the Madison Canyon are also called upon to furnish power to other corners of the territory covered. One pole-line runs to Bozeman, Livingston and Billings respectively, coupling up with the small local generating stations at the two last-named points, and thus linking these areas with the main network to ensure supply in the event of the local generating plants failing. Another line extends north to furnish power for the manufacture of cement at Trident, while a third line bears to the south to feed the dredges engaged at Ruby for the recovery of gold with the requisite energy. These are 50,000-volt lines, the pressure being broken down at various points *en route*, or at their outer terminals, to the local requirements.

A conspicuous feature of the high-tension 110,000-volt distribution system are the lines which conduct current for the operation of the 440 miles of the Chicago, Milwaukee and St. Paul Railway, between Harlowton and Avery. These lines feed into the high-tension bus-line 440 miles long, built by the railway between the two points in question, which runs parallel with the transcontinental track. The greater part of this work was carried out in 1915, during which year 375 miles of new 110,000-volt lines were erected chiefly to meet the immediate requirements of the railway company mentioned. At the same time, however, these routes of power are available for any local industries which may develop throughout the country traversed.

THE TRANSMISSION ENGINEER'S FIGHT AGAINST NATURE.

Towers erected on the side of the cliff along Beaver Canyon for 10 miles—typical construction among the Rocky Mountains.

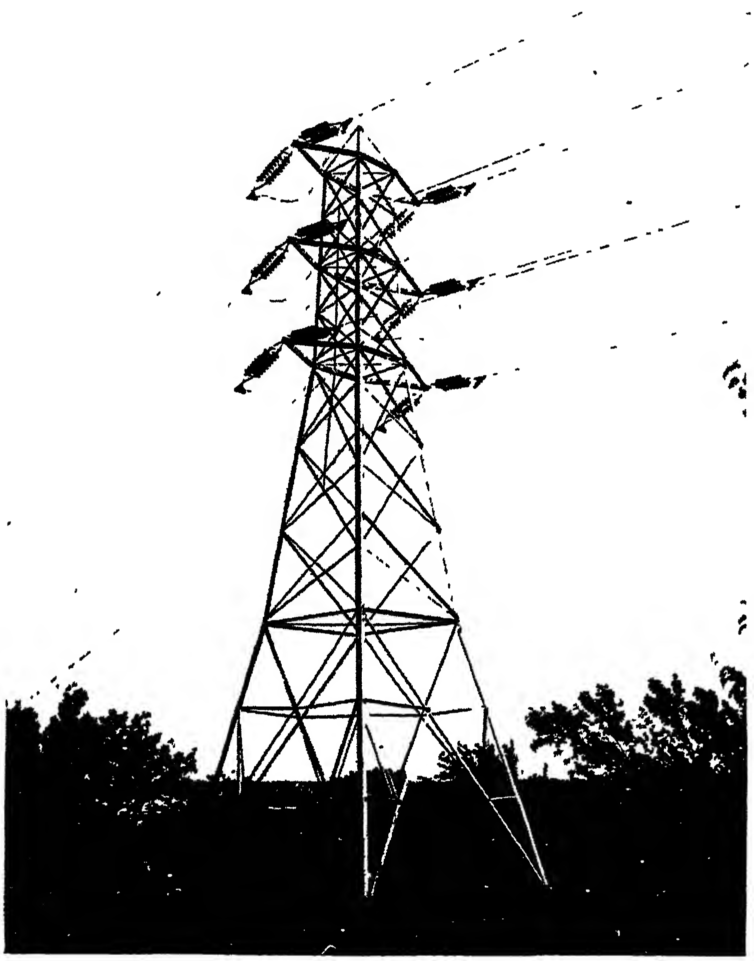
One of the most interesting of the Montana Power Company's express lines is that extending from the Rainbow Falls development on the Missouri River to Butte, a distance of 130 miles, and thence on to Anaconda, a further 32 miles. This is a duplicate line, the wires being strung on separate poles and running parallel along the one right of way. The wires, of hard-drawn copper strand, are carried on lofty four-legged steel towers with cross-arms. The three wires are suspended



THE "EXPRESS" TRANSMISSION LINE OF THE MISSISSIPPI RIVER POWER CO., WHICH CONVEYS CURRENT FROM KEOKUK AT A PRESSURE OF 110,000 VOLTS TO ST. LOUIS, 144 MILES AWAY.

In order to erect the line 1,320 acres of farming land had to be purchased from no fewer than 451 different owners. Stability is the keynote of its construction. Each tower is embedded in concrete so that it may stand secure in the violent storms common to this part of the country. The cables are spaced 10 feet apart vertically and 12 feet apart horizontally. A steel guard cable, $\frac{3}{8}$-inch diameter, is carried by the tops of the towers, and, being frequently earthed, protects the copper cables against the ravages of lightning.

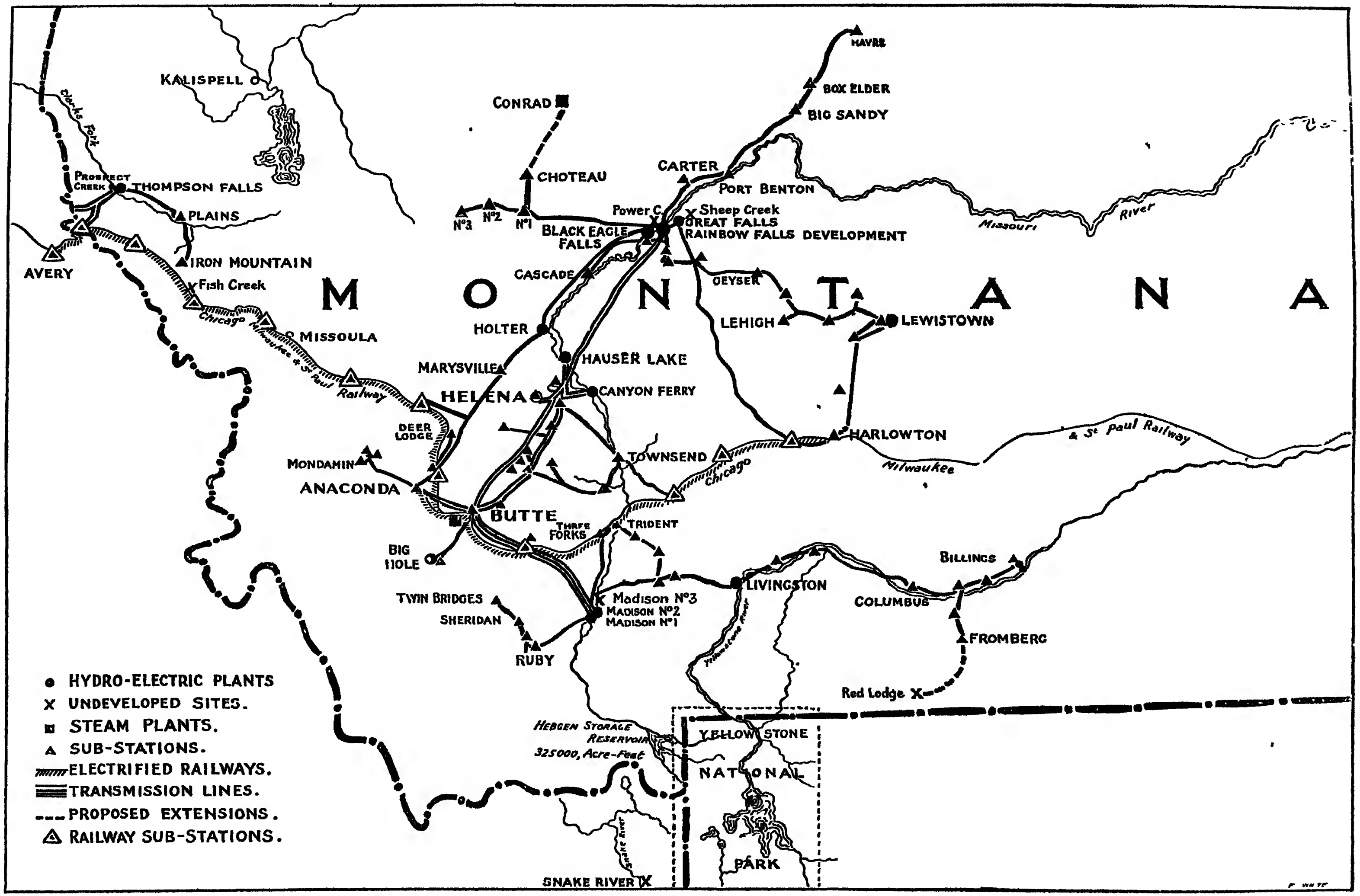
in a horizontal line from the cross-arm, one at each end and the third in the centre, by means of disk insulators. Each insulator is built up of 6 of these disks, each of which measures 10 inches in diameter. These insulators are capable of standing-up to a wet test exceeding 300,000 volts. Above the power wires, and symmetrically disposed in regard thereto, are two galvanized steel strands ·375 inch diameter, which are grounded at each tower, and which serve as a protection against lightning. Half-way between the generating station and Butte a switching station is provided, which is equipped with oil switches and lightning arresters. By means of this provision a cross-over connexion can be made, enabling one-half of either line to be cut out while the other is in operation. Moreover, each line is subdivided into seven sections by means of outdoor disconnecting switches employed for dividing the line into sections to locate any trouble that may have developed.



ANCHOR TOWER ON THE ST. LOUIS 110 000 VOLT EXPRESS LINE
At short intervals these steel towers, which exceed 10,000 lb. in weight, are introduced to support the line. The total weight of steel worked into the 1,062 towers is over 4,000 tons.

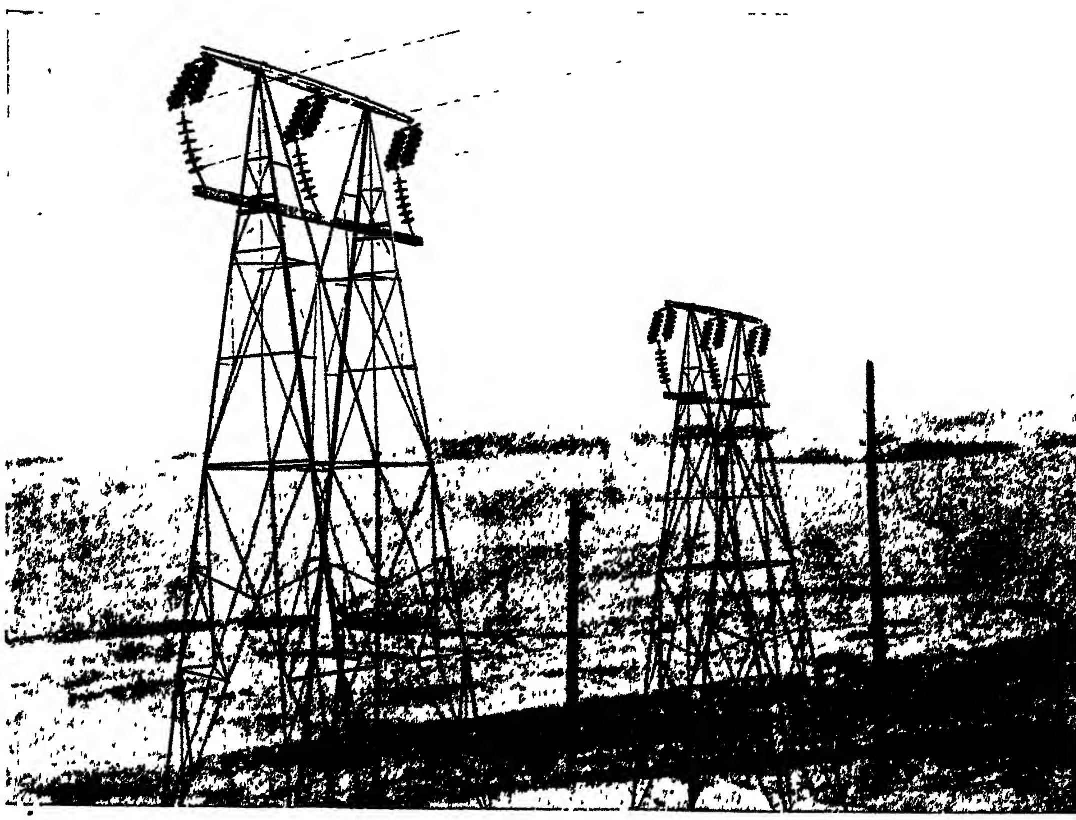
We are apt to marvel at the audacity of the railway engineer who, in order to overcome the towering Rocky Mountains on his way from coast to coast, lifted his tracks to dizzy heights, but his work is paralleled by that of the transmission engineer. The Montana Power express line from the Rainbow Falls to Butte traverses some of the most broken country it is possible to conceive, and is, moreover, called upon to negotiate the Continental Divide. At the Rainbow Falls, where the line springs from the generating station, it is at an elevation of 3,200 feet, but, in the course of its 130 miles run, it has to climb to 8,200 feet to overcome the mountain backbone of the country. Then it drops steadily to 6,100 feet, the elevation of Butte above sea-level.

When traversing the mountains the line engineer seizes upon any foothold that presents itself for the accommodation of his towers, and does not hesitate to sweep across ravines in a single leap. When the going is easy and the country tolerably



SKETCH MAP OF THE MONTANA POWER CO.'S SPHERE OF OPERATIONS.

The distance between Harlowton and Avery on the Rocky Mountains section is 440 miles. The area supplied by this undertaking, exclusive of Thompson Falls district, measures 300 miles from north to south and 260 miles from east to west.



NEGOTIATING THE CONTINENTAL DIVIDE BY MONTANA POWER "EXPRESS" TRANSMISSION.
How the current, at a pressure of 110,000 volts, is carried through the snow-swept reaches of the Rockies, showing details of work at points where the line describes a bend or angle.

level, the towers of the Montana Power Company's express lines are set about 600 feet apart, and this spacing is maintained as regularly as possible. But among the mountains the spans are exceedingly irregular in length. In crossing the Continental Divide they run up to 1,500, 2,000, and even more feet in length.

The most remarkable single span on the whole system is that carrying the conductors across the Missouri River. The lines are brought to the crown of a towering hump, from which the river below appears to be a narrow silver streak, contrasting vividly with the drab tone of the mountains. The engineer did not trouble to swing down the mountain side to a favourable elevation, because more than half a mile away, upon the opposite side of the river, another friendly ridge looms up. Accordingly, he planted his towers on the opposing bluffs and strung the wires between them, the length of the span being 3,034 feet. If one stands beside the towers on the lofty prominence and keenly searches for the support on the opposing cliff, even in the clearest weather one will only just be able to descry its slender, spidery form. The eye, picking up the wires at the tower beside which one is standing, can follow their track through the air, and the graceful curve they describe in the sweep across the valley, but for a considerable distance before the opposing towers are reached by the sight the conductors seem to have dissolved into the rarefied mountain air.

In contradistinction to the express or trunk lines are the networks of distributing lines radiating from the sub-stations throughout the consuming areas. Here the array of wires may be so intricate as to present a baffling tangle. In point of

superficies the district thus covered may not be impressive, but the mileage of wires which have to be installed, and the complexity of the incidental auxiliary apparatus, may easily assume a total which appears to be out of all proportion to the duty fulfilled. In these circumstances it is not surprising that a power company strives to dispose of its energy in big blocks.

What distribution of current for lighting and heating shops, offices and private residences means to a large power-supply undertaking is revealed by this company. It has many individual clients each of whom consume in one year, as already stated, more power than the whole of the private customers, distributed over an area of 78,000 square miles, combined. The supply of 18,000,000 kilowatt-hours to 38,665 private customers for lighting demands the installation and maintenance of 24,344 poles carrying 61,525 cross-arms upon which are mounted 240,684 insulators to support 4,200 miles of wire. To break down the current to the necessary pressure requires 57 sub-stations with 2,621 transformers; while the recording of the current thus consumed involves the installation and maintenance of 38,665 meters, the readings of which have to be transferred to 38,665 book accounts. On the other hand, the supply of 18,000,000 kilowatt-hours to a single customer for power involves the provision of only one sub-station, one service installation, a solitary meter, and one book account.

THE "AIR-LINE" ROUTE OF THE TRANSMISSION ENGINEER.
In Montana his task is by no means easy. His method of tackling natural obstacles is here illustrated by the direct approach of the lines from the lowlands to the mountains in the distance.

THE FIRST ILLUMINATION OF NIAGARA: THE AMERICAN AND BRIDAL-VEIL FALLS.
This inaugural scheme of flood-lighting was evolved and carried through by Mr. W. D'A. Ryan.

Wonders of Illumination—I

THE DEVELOPMENT AND ADAPTATION OF FLOOD-LIGHTING

SPECTACULAR electric lighting had its origin as a side-show in connexion with the International exhibitions which have been held from time to time in various countries. Difficulty was experienced in rendering these centres sufficiently attractive at night. The beauties of the buildings, their graceful architectural lines and sculptural embellishments, were lost to the eye after darkness had cast its pall over the scene.

Many attempts were made to overcome this drawback but in vain, inasmuch as the available mediums of illumination did not readily lend themselves to the presentation of spectacle in light and flame. When electric lighting was sufficiently perfected to emphasize its reliability and safety, it was realized that additional attractiveness might be extended to such ephemeral institutions. The first attempts were primitive, being confined to the draping of the main buildings with strings and festoons of vari-coloured electric incandescent lamps. These fulfilled no other purpose than to attract attention by the apparently prodigal display of light. They could not be considered as part of a co-ordinated scheme of decoration.

But the very crudity of the idea stimulated ingenuity and thought, with the result that, in due course, the practice of limning the outlines of the buildings in dots of light by the more or less symmetrical distribution of incandescent electric lamps was developed to a high degree. This practice honoured the principle of utilizing the buildings themselves as the background for the lights and, to a certain degree, the project was attended with success. But the arrangement suffers from one serious inherent disability. The buildings are merely employed as a means to an end. From a distance a certain fairyland aspect is imparted, especially by the skilful em-

ployment of broad colour effects, but the architectural and decorative features of the buildings, appreciated under daylight lighting, become suppressed.

When it was decided to celebrate the opening of the Panama Canal and the wonderful commercial advance of the Pacific Coast at San Francisco by an International Exhibition in 1915, those associated with the enterprise decided that the illumination should be carried out along lines never previously attempted, and should be as remarkable in the novelty sense as human ingenuity could contrive. In 1912, when the plans were first seriously discussed, it was decided to signalize this new departure by the creation of a "Chief of Illumination," who should be wholly responsible for the lighting of the exhibition, and that his scheme should form as essential a part of the whole as the work of the architects, sculptors and artists.

Those fathering the exhibition were persuaded to take this action by a sensation which had been created at Niagara Falls. For the purpose of imparting attraction to that wonderful cascade of water by night, an astonishing scheme of flood-lighting had been evolved by Mr. W. D'A. Ryan, consulting illuminating engineer to the General Electric Company, of Schenectady. By the artful disposition and skilful use of his scintillators, he succeeded in investing the tumbling water with a new and hitherto unsuspected charm. Crowds flocked to Niagara during the brief period the experiments were in progress; the novelty of viewing the tumbling water infused with a riotous blaze of colour, made a wonderful appeal. The experiment in its scientific aspect was of significant import, inasmuch as it conclusively proved that in electricity the engineer was provided with a medium for securing effects in lighting such as had never before been contemplated or considered possible.

Flood-lighting Remarkable

When Mr. Ryan received an absolutely free hand in the elaboration of the illuminating scheme for the Panama Pacific Exhibition, he decided to conduct his work upon the most imposing scale—one in keeping with the character of the exhibition itself. In daring, novelty, spectacle and artistry his achievement is conceded to have been an overwhelming success. He ushered in a new era so far as spectacular artificial illumination is concerned—an era endowed with illimitable possibilities. His responsibility was not confined to the fulfilment of the electrical engineering aspect of the issue, pure and simple, but was extended to the selection of the glass and other transparent and reflecting mediums employed in the construction.

Upon this occasion the practice of stud-lighting the buildings was wholly abandoned in preference to indirect, concealed and direct lighting *en masse*. By the skilful disposition of the lamps it appeared as if many of the objects and buildings were endowed with innate radiance; this was due to the setting of the lights within the objects themselves. Similarly indirect lighting, by the aid of concealed projectors, the beams thrown from which were woven into a uniform blaze of light and colour, revealed all the beauties of the sculpture to an extent never previously believed to be possible. The control of the masses of light in such a manner as to impose no strain upon the eyes aroused widespread comment, because even the most powerful white beams thrown by the large searchlights, by skilful blending with the coloured glows from other lamps, were completely tamed, and that without any sacrifice of lighting value.

The "Tower of Jewels"

The most conspicuous feature of the exhibition was the lofty campanile, 435 feet in height, known as the "Tower of Jewels." This was embellished with more than 100,000 "Nova-gems" or property

jewels devised for this express purpose. At night it was a conspicuous landmark for miles around, transformed as it was into a shimmering blaze of light and colour. Around the base, and so set upon the roof of the main building as to be invisible from the boulevards below, there were lines of projectors, the beams from which were so skilfully interwoven as to throw a massive sheet of light enwrapping the tower from base to pinnacle. The luminous flood not only threw the pile into striking relief against the black background of the night, but catching the facets of the crystals, caused them to reflect all the colours of the rainbow, irrespective of angle of view. The flood of light was supplemented by a blaze of illumination thrown from cleverly concealed lamps; these were arranged in recesses and at the base of the supporting columns. The concealed lights had a distinct soft tinge which, while blending harmoniously with the flood of white light from the projectors, at the same time appeared to cause the tower to glow with a soft rich phosphorescence of its own.

Clever Illusions

Another fascinating effect, due to the clever arrangement and manipulation of the tonal effects, was produced in a fountain symbolizing the formation of the earth. The *vraisemblance* of the Void was obtained by producing the illusion of mysterious vapours arising from huge cauldrons. In another instance there were two fountains symbolizing the rising and the setting sun respectively. The spray of water was hurled to a height of 95 feet, and the shaft and ball of each fountain was glazed with heavy opal glass, behind which were placed the maze of lamps. During the day every indication that these globes formed sources of illumination was concealed, inasmuch as they were so finished externally as to convey the impression of having been wrought from travertine stone. The electric lamps placed within had a collective lighting power of 500,000 candles, but although the volume of light was intense, the intrinsic brilliancy was so low as to give a soft radiant glow extremely restful to the eyes. At the same time, however, the light shed from this source was adequate to illumine brightly the whole of the court, aggregating some 500,000 square feet, in which the fountains were playing.

The perfect control of the light and the skilfully contrived rich toning enabled the beauty of the architectural lines and decorative mural work of the artists to be presented to the utmost advantage. Harsh and grotesque shadows were completely eliminated. The finest sculptural detail could be studied as easily under artificial as under natural lighting conditions. Moreover, the colour scheme and control were so delicately adjusted as to permit the change from daylight to night lighting to be carried out gradually and imperceptibly without the slightest jar to the æsthetic sense.

Artificial "Sunsets"

As the sun sank lower and lower, the artificial lighting was switched on gradually to gather intensity as the daylight waned. Pacific sunsets are widely famous; the vanishing sun and the long angular rays yield wonderful colour schemes. The illuminating engineer had made a close study of these natural phenomena in elaborating his designs, and set out to continue Nature's scheme. Thus, under the setting sun, the Tower of Jewels assumed a wonderfully rich tone, while the jewels flashed and scintillated as does the glacier upon the mountain peak under the self-same conditions. The artificial light slowly brought into action, took up the beautifying work of the setting sun, and impalpably increased in brilliancy before the creeping shadows of the night; the final mergence into normal illumination escaped detection because the evolution was so delicately adjusted.

FIRELESS FIREWORKS—A SPECTACULAR NOVELTY OF THE ILLUMINATING ENGINEER.

The perfection of electric lighting has opened up a new era in pyrotechny. The arresting feature portrayed above was introduced by Mr. D'Arcy Ryan at the San Francisco Exhibition. By the aid of steam and smoke he prepared a grand finale. To heighten the effect of the "set piece" a mammoth locomotive, supported on a special stage, was driven at 60 miles an hour. The wheels revolved madly, and immense clouds of steam and smoke were hurled into the air, upon which were played vari-coloured electric lights, conveying a realistic impression of a genuine firework display.

Another group of imposing buildings, owing to the colour scheme adopted, assumed a rich ruby tone under the setting sun. The artificial lighting took up Nature's colour-clothing task, but suffused the buildings a deeper and richer red, somewhat reminiscent of the glow thrown by molten iron. Scarcely had this effect attained its maximum when the tone gradually melted into a delicate rose, an effect secured by switching on the flood-light projectors, with their sheet of white flame, to mingle with the rich red shed by the concealed electric lamps. As the white light gradually approached its maximum intensity many rich and wonderful tints were produced. The skilful weaving of the red with the white light converted the material of which the buildings were constructed into an exquisite imitation of soft Italian marble. The banners waving in the wind were translated into sheets of waving fire. At the base of each staff a deep ruby-coloured concealed light was placed, and in such a manner as to throw the whole of the ray upon the banner only, so that no matter in which direction the latter was blown by the wind it resembled a tongue of flame.

The purely spectacular effects, those avowedly of a nature to arrest the attention of the masses, were every whit as striking. Upon the water front of San Francisco a specially trained company of American naval marines was stationed. They were equipped with a battery of forty-eight 36-inch searchlights, having an aggregate luminosity of 2,600,000,000 candles. These searchlights were set out in accordance with the illuminating engineer's plans to form an integral part of the whole scheme. They were brought into action as the day waned, and so assumed the functions of the sun disappearing below the horizon in a blaze of light and colour. Huge spokes of light were projected towards the zenith, the shape and form of the ray becoming accentuated as the daylight faded. When darkness had completely invested the scene the hemispherical display of shafts of light gave an impressive blaze, recalling the Aurora Borealis, which was visible for a distance of 50 to 60 miles.

A Battery of Searchlights

The searchlights were also employed for divertisements. The marines had been perfected in special drill with the lights, which was carried out with characteristic naval precision. By the manipulation of the searchlights and the interposition of the beams they were able to form gigantic rings of light in the sky—rings suggestive of those blown in smoke from a pipe or cigar. They also carried out such effects in the sky, by the introduction of colours, as the production of "Scotch Plaids," the "Birth of Colour," a weird "Ghost Dance," "Fighting Serpents," and the "Spook's Parade," to mention only a few of the fascinating performances which were regularly displayed against the black background offered by the heavens. More than 300 different scintillating effects were worked out, and it was discovered that changing atmospheric conditions afforded additional scope in this connexion.

Colour Effects

Special effects were also employed to celebrate notable events. Thus on St. Patrick's Day every light, including projectors and searchlights, was fitted with a green screen, the whole of the Exhibition appearing to be bathed in an emerald tone. Orange Day was similarly honoured only, in this instance, instead of a single colour being employed for screening the lights, varying tones of orange were employed. The great spectacle was that recording the ninth anniversary of the destruction of San Francisco by earthquake and fire. On this evening the whole of the buildings were bathed in a fiery red, and, by cunning manipulation of the lights and the introduction of effects for the

occasion, a strikingly realistic illustration of the destruction of the Tower of Jewels by fire was presented.

" Fireless Fireworks " was another attractive feature, and served to bring home the brilliant pyrotechnic displays possible with electrical illumination. The effects presented included " Chromatic Wheels," the " Devil's Fan," " Sun-burst," " Fairy Feathers," and " Plumes of Paradise." Smoke and steam in profusion formed the accessories upon these occasions, the atmosphere thus created being the target of the scintillators and searchlights in accordance with a carefully prearranged schedule. Steam and smoke were produced in the main by a novel expedient. A monster locomotive was so set up as to be driven at a speed of 50 to 60 miles an hour, the wheels spinning madly, though the engine, of course, was held stationary. A full head of steam was maintained while the fire was stoked more vigorously than would ever be recorded under actual running conditions. The result was that steam poured from every outlet of the engine, the safety-valve blew off at full-cock, sending a white shaft high into the air, while huge dense volumes of smoke were belched from the funnel. The lights dancing upon the escaping clouds produced a striking resemblance to an actual firework display, while the noise of the escaping steam and coughs of the locomotive heightened the illusion, recalling the hissing, spluttering and detonation incidental to the firing of a huge set-piece.

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FLOOD-LIGHT ILLUMINATION OF THE GLASGOW MUNICIPAL BUILDINGS.

A battery of special flood-lighting projectors set upon the roof of a building opposite. This battery illumined one half of the home of the City Fathers. A similar battery was disposed at another convenient position to illumine the building from the opposite end. In this way a sheet of light of uniform intensity was projected upon the façade.

The striking success attending flood-lighting in the interests of spectacle and artistry, and the deep impression which such effects exercise upon the public mind, has induced the application of the idea to Great Britain and other European countries. The principle is freely employed for the embellishment of public buildings, monuments, and commercial palaces in the spectacular sense, and for the illumination

By permission of the British Thomson-Houston Co., Ltd.

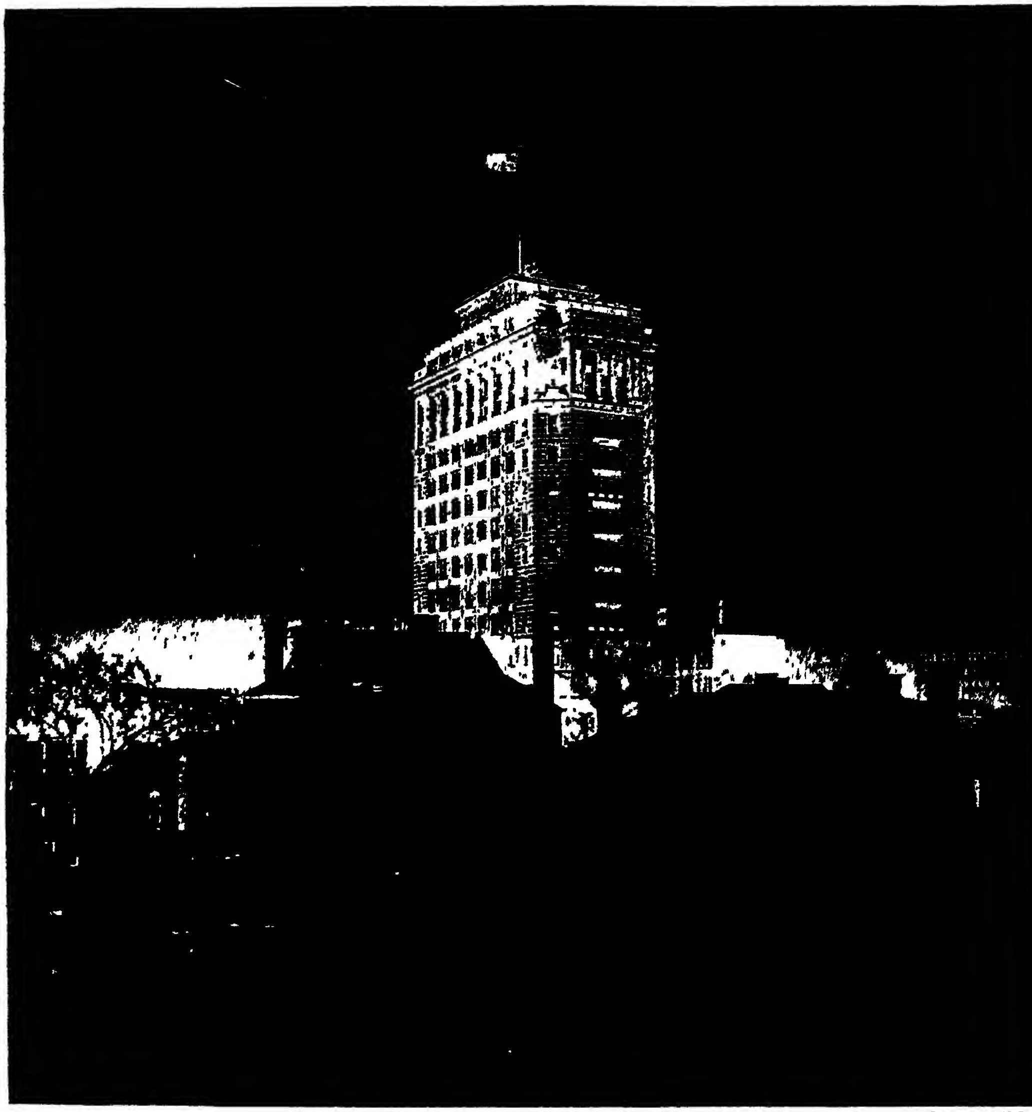
THE FAÇADE OF THE GLASGOW MUNICIPAL BUILDINGS UNDER FLOOD-LIGHTING

For this illumination some 70 projectors, arranged in two groups, were required. The central tower was illuminated by two projectors disposed upon the roof. From an untouched photograph by W Ralston

many other purposes, especially those of an avowedly commercial character. This art, for such it may be called, has been carried to its highest stage of development in the United States of America and Canada, although there are indications that it is destined to be employed upon a less ambitious and comprehensive scale in of railway bridges, both above and below, to facilitate the movement of traffic by rail, road and water. As a vehicle to arrest attention, the principle can scarcely be excelled—at least, not so inexpensively.

For the execution of this work a special form of projector has been evolved. While the various types introduced vary in detail,

they are basically identical. As the installation must necessarily be planted in an open position, such as the roof of a building, it is essential that the require-



By permission of the General Electric Company, U S A

A SKY-SCRAPER AS "A PILLAR OF FIRE BY NIGHT."

The Bell Telephone Building in Philadelphia as portrayed by flood-light. The projectors are placed on the roofs of facing buildings and so adjusted as to cover the whole of the building. The flag is illuminated by projectors, placed near the bottom of the flagstaff.

ments of weather-proofness should be completely satisfied. The lamp must also be adequately provided with ventilating facilities.

It is equally incumbent that the lamp should be of relatively small proportions to admit its installation in cramped or otherwise difficult positions. One type extensively used has been evolved by the British Thomson-Houston Company. This permits mounting on either a tripod or bracket; the lamp is carried in a crutch to permit swivelling for adjustment of the lamp to any angle in the vertical plane. Another type, somewhat recalling the familiar automobile head-light, is carried

upon a universal mounting, allowing it to swing in both the horizontal and vertical planes; and because of this convenience it is suitable for attachment to parapets and cornices of buildings which would not permit the employment of the more widely practised form of mounting.

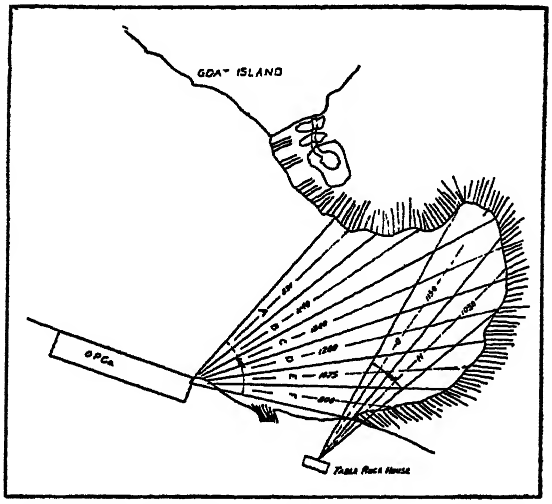


DIAGRAM SHOWING THE METHOD OF FLOOD-LIGHTING THE HORSESHOE FALL,
and the laying-off of the illuminated area into 10-degree zones.

The reflector, another important adjunct, may be of aluminium, vitreous enamel, or a plain or diffusing mirror. From the point of view of light concentration the plain mirror is satisfactory, but the illuminated disk is somewhat uneven, owing to the reflection of the lamp filament. This shortcoming can be met and a more uniform flood of light obtained by using a diffusing glass in front of the lamp. Indeed, this device is generally advocated whenever a gas-filled lamp is employed as the illuminant, to avoid striation of the light.

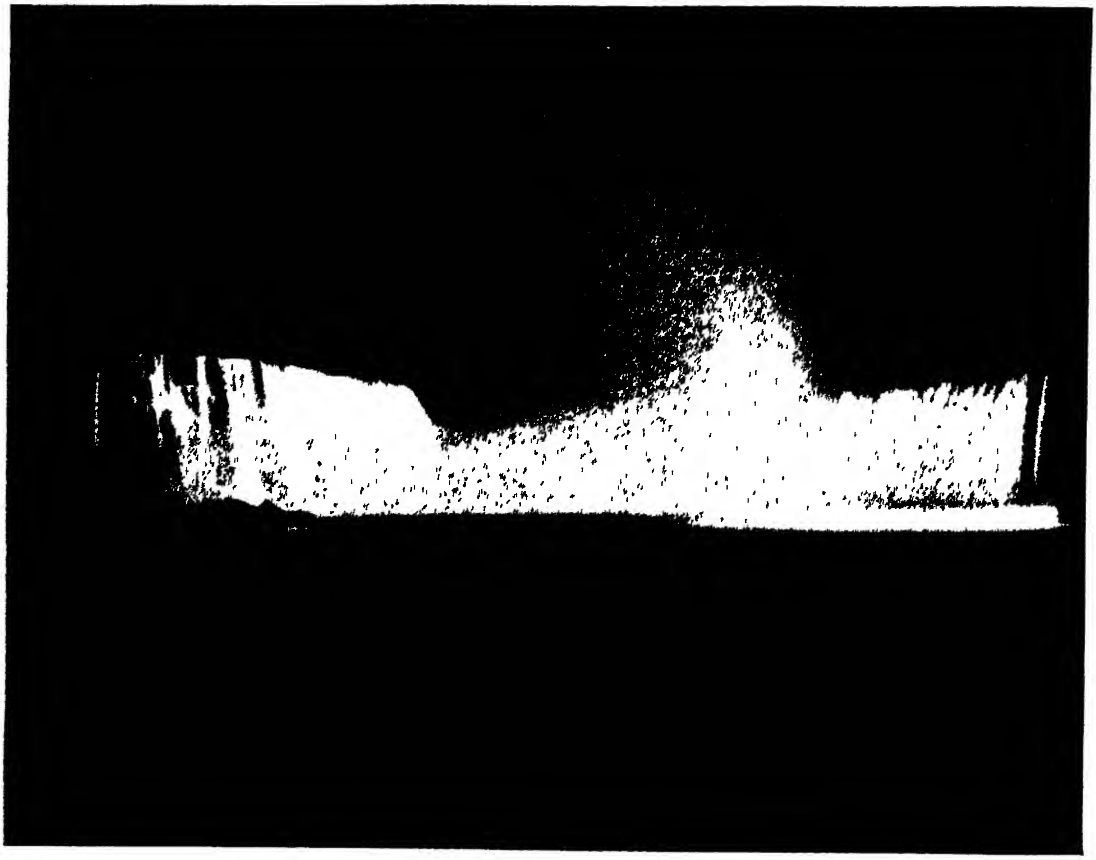
Having obtained the beam of light the illuminating engineer is able to produce "effects." As is well known, the disk of light thrown from a projector in normal circumstances is circular, but such a disk is not always satisfactory or even advisable; for instance, in the illumination of rectangular buildings a pronounced proportion of the beam must fail to fall upon the objective. Under such conditions the engineer seeks to project an elliptical disk by the aid of a "spreading glass" attached to the front. Of course, an elliptical disk can readily be obtained by projecting the ray angularly upon the object, but this method suffers from one drawback. The surface nearest the projector is more brilliantly lighted, and the result is patchy.

An interesting example of the arresting effect which can be accomplished by means of flood-light projection was afforded at Glasgow, when the City Buildings were limned in this manner upon Peace Night, 1919. To illumine the extensive horizontal façade of the building, some 70 projectors were required. These were divided into two batteries, placed in two favourable positions upon the roofs of conveniently facing buildings at each end, to secure an oblique beam or angular throw. Each battery was in two lines, one above the other, the front lower line being depressed to light the bottom half of the building; while those in the rear upper line were either poised horizontally or slightly inclined to light the upper part of the façade. In addition, subsidiary projectors were mounted upon the roof of the building itself, and tilted upwards so as to throw a white sheet of light upon the central tower.

Upon the American continent the practice of illuminating façades of buildings is more pronounced; in this instance the major dimension of the rectangle is generally in the vertical plane, owing to the vogue of the sky-scraper. Illumination is somewhat more difficult because the buildings offering a friendly station for the receipt of the projectors are sometimes relatively low, as in the city of Philadelphia, where the Bell Telephone Building, converted into "a pillar of fire by night," towers high above its neighbours. Seeing that it is not advisable to project the beam

at an angle exceeding 30 degrees, ingenuity has to be exercised in the disposal of the battery of lamps to ensure the adequate illumination of the upper levels of the skyscraper, owing to the length of the throw. To compensate for this disadvantage the special lamps which have been designed for flood-lighting are generally favoured in preference to the gas-filled lamp. In the case of the Bell Telephone Building the spectacular effect is enhanced by the skilful disposal of projectors at the foot of the flagstaff crowning the pile. These are set in such a manner as to cause the skyward pointing beams to play upon the flag, which thus becomes converted into what appears to be a streamer of white or coloured light.

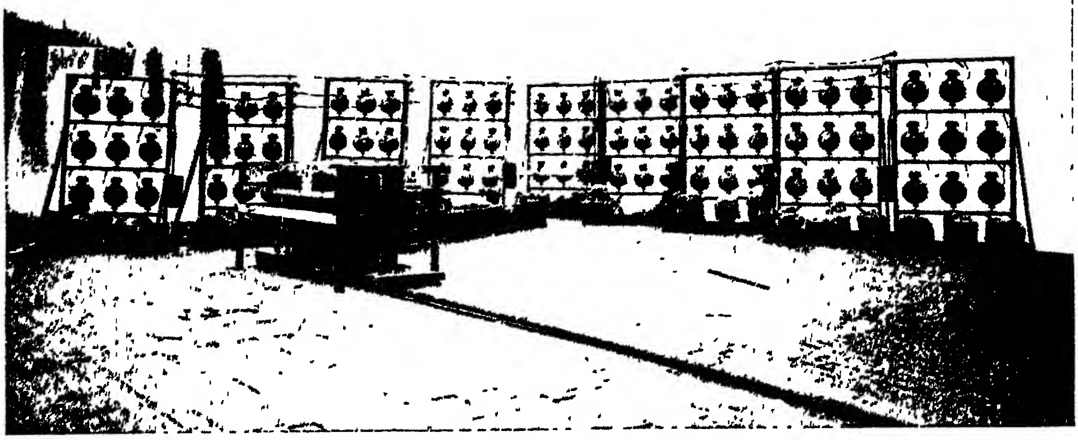
While the night illumination of the Niagara Falls has been abandoned upon the American side, it has been retained upon the Canadian bank, through the enterprise of the Hydro-Electric Power Commission, of Ontario.



A FAIRYLAND ASPECT OF THE HORSESHOE FALL, NIAGARA

For the illumination of the majestic cascade upon the Canadian side of the river, there are 91 projectors. The throw of the beam varies from 600 to 1,300 feet. The spray rising in the centre appears to be transformed into smoke by the intense brilliancy of the flood of electric light.

The complete illumination of the Horseshoe Fall presented a pretty lighting problem, and demanded prolonged observation of the tumbling waters under all and varying conditions, and the general behaviour of the spray, to ensure the projectors being set in the most favourable position. It was ultimately found that the most advantageous site was offered by the roof of the generating station of the Ontario Power Company, supplemented by a subsidiary and smaller battery upon



HOW THE HORSESHOE FALL IS ILLUMINATED AT NIGHT.

The main battery of 81 projectors, disposed in nine groups of nine lamps each, is set upon the roof of the station of the Ontario Power Company, a short distance below the cataract. Each projector is fitted with a 1,000-watt gas-filled lamp.

the top of Table Rock House. Situated below the cascade the former not only secures an unobstructed view of the Horseshoe Fall, but is out of the way of the public, and also immediately contiguous to the source of power. The subsidiary installation upon Table Rock House was determined upon because under certain conditions of wind and spray the crest of the Falls is rendered invisible from the powerhouse. As, however, Table Rock House could ensure the illumination of the crest under the unfavourable conditions, it was decided to plant thereon 10 narrow-angle projectors. The provision of this subsidiary battery has been found to enhance the general effect very appreciably.

Experiments led to the decision to adopt projectors throwing a beam with an angular spread of 10 degrees. The length of contour in the selected angle of illumination is about 2,000 feet, while the height of the wall of water is 158 feet. The area of the field illuminated is about 316,000 square feet. The contour of the Falls to be lighted was laid off in 10-degree zones. The field covered by the main battery is thus divided into six zones, while two zones are overlapped by the subsidiary projectors. The throw of the beam in the case of the first-named varies from 800 to 1,300 feet. The engineers had to determine the number of projectors necessary for each zone, to secure as far as was practicable uniform illumination over the whole area.

The main battery of projectors comprises 81 searchlights set out in nine units, each comprising three rows of three lamps each. Each projector is fitted with a 1,000-watt gas-filled lamp of the regular type. There are three 30-kilowatt transformers placed centrally to the projectors, and connected to the switch in the powerhouse beneath by lead-covered cable in conduit, the current being drawn from the 2,200-volt service-bus in the station. On the low tension side weather-proof cable is used for feeders; while there is also an enclosed main switch with fuses and a service-bus enclosed in a wooden case on each bank. The secondary battery, on top of Table Rock House, comprises 10 projectors and these are equipped with 500-watt flood-lighting lamps; this type was selected in this case for the greater concentration of beam produced thereby. Current for this auxiliary battery is drawn

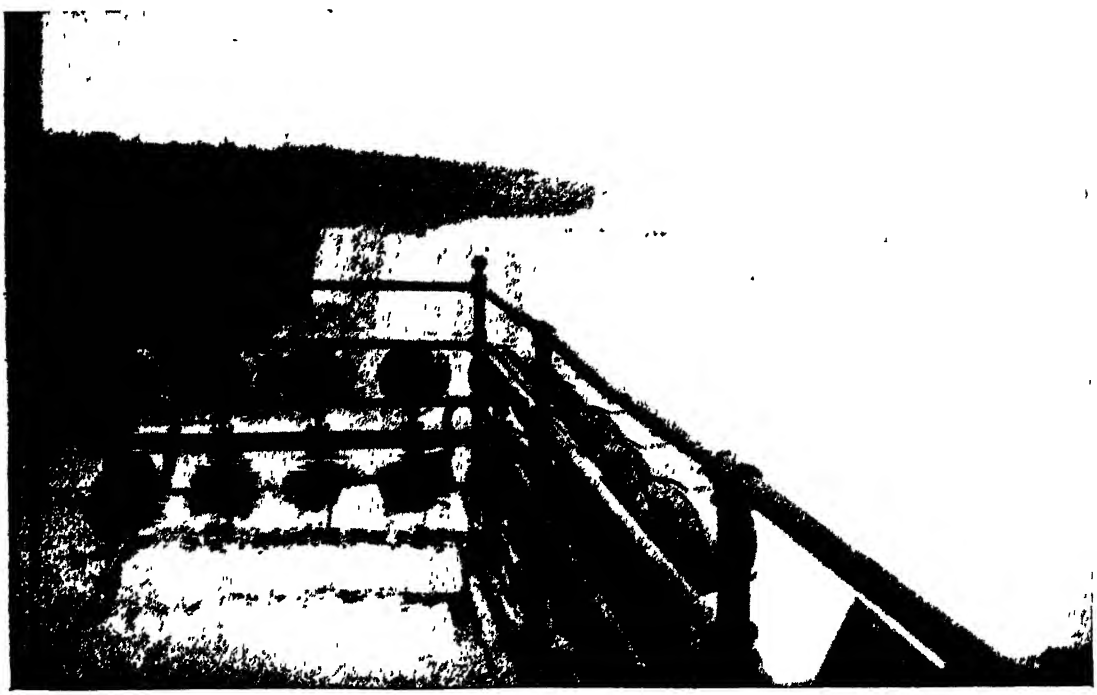
from an adjacent line. All connexions from the feeders to the lamp-sockets are made by rubber-covered wire in flexible conduits. This arrangement was adopted to avoid strain upon the wires in winter from the accumulation of ice.

The beams are projected in such a manner as to bring the top edge of the shaft of light upon the crest of the Falls. Naturally, in those instances where the beams have to be thrown the greatest distance, the diameter of the beam at the point of incidence exceeds that of those which have the least distance to traverse, because the beam is in the form of a cone, of which the lamp forms the apex. The excess beam diameter is therefore employed for lighting the water at the foot of the Falls, and the projectors are adjusted to this end.

From the spectacular point of view the effect is exceedingly impressive. The water, when a clear view is obtained, appears to be cut in glass; its steady movement over the cliff causes it to glitter brilliantly. As a rule the extreme edges of the Fall stand out sharply, but in the centre there rises what appears to be a huge fountain of smoke, issuing as it were from a mighty cauldron; the illusion of movement is accentuated by the steady character of the beam playing upon the intangible mass which is naturally the sport of the wind.

In still weather the ascending column is virtually stationary, but, under contrary wind conditions, it is persistently being driven from one side of the ravine to the other.

The installation was carried out to commemorate the visit of H.R.H. the Prince of Wales to the Niagara Falls on October 18th, 1919.



THE SECONDARY FLOOD-LIGHT INSTALLATION FOR ILLUMINATING THE HORSESHOE FALL.

As the crest of the Fall is screened by the spray under certain conditions of wind, a group of ten narrow-angle projectors, carrying special flood-light lamps, are mounted upon the observation gallery of the Table Rock House.

GENERAL VIEW OF THE ANDERTON BOAT LIFT AFTER ELECTRIFICATION

The illustration shows the overhead gear, including the 72-inch pulley-wheels, over which are passed the cables attached to the counterweights. By means of this lift, canal craft are passed vertically through the 50-feet difference between the levels of the river Weaver and the Trent and Mersey Canal System.

A Novel Lift for Boats

HOW THE ELECTRIC CURRENT FACILITATES CANAL TRANSPORT IN ENGLAND

IN the days preceding the weaving of the railway network now enmeshing Great Britain, industry was dependent upon the various waterways for the cheap transport of its raw and manufactured materials. Among the links of this character to be pressed into such service was the river Weaver. This modest Cheshire waterway became of decided commercial importance by extending to the Cheshire salt and chemical industries, pivoted upon Northwich, an outlet to the sea via the river Mersey, into which it empties near Runcorn. The control of this channel of communication became vested in the River Weaver Navigation Trustees; through their enterprise it was rendered navigable by steam barges of 300-tons burden to Winsford, about twenty-one miles above its confluence with the Mersey. To-day the

tributary does not discharge directly into the river, but into the Manchester Ship Canal, through the locks at Weston Point.

Water communication extending into the Midland area was desired, and, in fact, was possible because at Anderton the river Weaver flows alongside the Trent and Mersey Canal system. Interchange of traffic between the two set in and developed rapidly, but was seriously handicapped by the necessity to tranship the goods at this point, because the river flows 50 feet below the canal. Transhipment of cargo not only proved expensive but involved loss of time, to avoid which the question of the feasibility of effecting a physical junction between the two waterways was raised. The advocates of the scheme suggested the obvious means to such an end, namely, locks, but when the engineer-in-chief to the Weaver Trust, who at that time was the late Sir Edward (then Mr.) Leader Williams, investigated the problem, he discovered that such a solution was impracticable. The introduction of locks would have necessitated the acquisition of a large tract of land, their construction would have occupied considerable time, while, finally, the operation of the locks would have withdrawn a huge volume of water from the canal.

Inasmuch as connexion was imperative, the engineer was forced to evolve another solution, if he could, and this assumed the form of a lift-lock between the two waterways, and operated in such a manner as to involve no loss of water from the canal. It was an interesting proposal, and further close investigation served to emphasize its practicability. Briefly, the project involved the provision of two troughs, of equal dimensions, each of which was to be charged with water, and in which the boats were to float to eliminate all possibility of their hulls being strained in the event of the cargoes shifting. Under this system one trough was to be elevated while the other was lowered, and they were to oscillate upon the counterbalancing system. Hydraulic operation was to be adopted by means of a vertical ram, or piston, moving up and down in a cylinder. A similar system for handling boats of larger capacity, it may be mentioned, has since been introduced upon the Trent navigation system in Canada.

A Lift-lock Projected

The fulfilment of this accepted proposal presented some interesting problems and entailed a considerable amount of work. There happened to be an island in the river, and it was decided that this would constitute the most favourable site for the lift. The canal had to be brought to this point, and this provision was fulfilled by building an aqueduct, as a spur to the line of the canal, at the normal level of the latter, across the river below to the island; the extremity of the spur was to form the opening for the passage of the boats to and from the lift.

Interesting Problems

The aqueduct is constructed of wrought-iron, is 162½ feet in length, 34 feet 4 inches wide, and has a water depth within of 5¼ feet; it is built in three spans, supported on cast-iron columns, which carry it to the top of the hydraulic lift-pit. As there are two troughs constituting the lift, the aqueduct had to be divided into two channels each forming an approach to the lift, and this was done by the introduction of a central web into the aqueduct, giving a fairway 17 feet 2 inches wide on each side. Consequently, there is no risk of a boat, waiting to enter the lift, obstructing the passage of one which is leaving the elevator. The final feature was the sealing of the end of the aqueduct when separated from the trough, to avoid loss of water. For this purpose two wrought-iron lifting gates were fashioned—one for each channel—and they were so set as to present when closed a water-tight end to the aqueduct. These gates each weigh 3,000 lb.

and are counterbalanced by weights working over pulleys. Originally they were manually operated, but have since been converted to electrical working.

The two troughs, in which the boats are lifted up and down, are of identical dimensions and weight, whether carrying a boat or not, because a boat with its cargo displaces an equal volume of water-weight. Thus it is immaterial whether a boat is lowered simultaneously with the elevation of another craft. Each trough measures 75 feet in length by 15½ feet in width and carries 5 feet of water. The trough may be described as an immense rectangular box, fashioned of cast-iron, and of special design to prevent the sides from bulging under the weight imposed from within. Each end of the trough is fitted and sealed with a water-tight gate, similar to that provided at each end of the canal aqueduct.

Features of the Original Installation

In the original installation each of these troughs was attached to the head of the hydraulic ram or piston by which it was moved up and down, the connexion being a socket 8½ feet deep fitting over the extremity of the ram. The latter was 3 feet in diameter, and at the bottom of the lift-pit or well passed through a stuffing-box and then through a tunnel into the press. The tunnel, which was 52 inches in diameter, was provided to allow access to the valve-box and glands of the presses, as well as the stuffing-boxes, and to the ram itself for lubrication when necessary. The presses were set below the bottom of the lift-pit within cast-iron cylinders, and as the rams themselves were over 50 feet in length they had to be continued below the floor of the lift-well for a corresponding distance.

The troughs had to be guided in their vertical travel, and this was assured by fitting guide blocks to the corners of each trough, which worked against guides on the columns suitably disposed around the lift-pit. This arrangement kept the troughs steady while in motion. The method of bracing the supporting guide columns, while appearing simple, was yet intricate, inasmuch as when working there was an aggregate of 500 tons in movement; each trough with its charge of water and boat represented some 250 tons. At the top of the lift-pit these columns supported lattice girders which carried a platform.

The Counterbalancing System

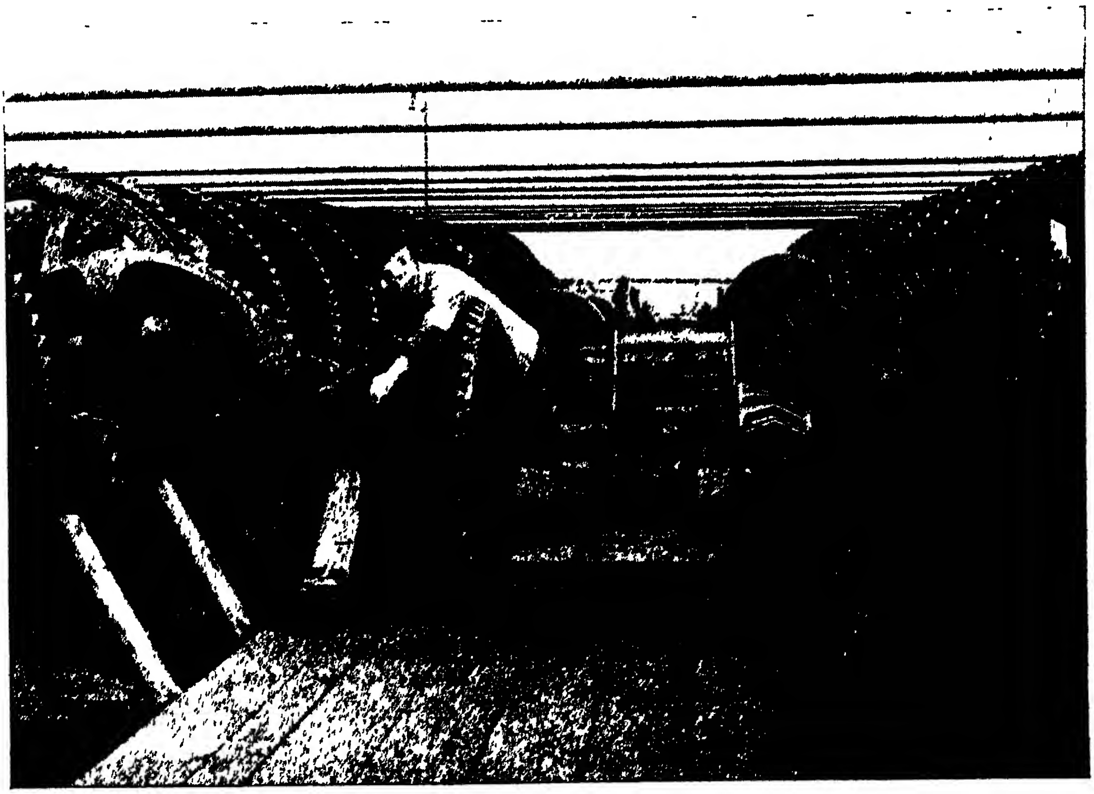
To effect the smooth and efficient working of the counterbalancing system adopted involved the necessity of somewhat complex mechanism. Each of the troughs was fitted with a number of syphons enabling the level of the water within to be adjusted to requirements. The actuation of the elevator was assisted by a hydraulic accumulator having a ram 21 inches in diameter by a stroke of 13½ feet. The two main presses were interconnected by a pipe, having a valve, for establishing or interrupting communication between them. Pipes and valves also extended from the accumulator to each of the presses, so that the accumulator could be employed to assist either or both presses. Then there were waste pipes to convey the spent water from the accumulator back into the aqueduct; it was imperative that loss of water from the canal should be reduced to the minimum.

The India-rubber Buffer

The operation of the hydraulic system demanded somewhat delicate control and skill, especially when bringing the rising trough to the level of the aqueduct, where, of course, a water-tight connexion between the trough and the aqueduct had to be made before the gates were lifted. This was done by facing the end of the aqueduct with thick india-rubber, which became compressed under the weight imposed by the trough. Then the manipulation of the

level of the water within the trough and the aqueduct had to be carefully adjusted before the gates were opened. While no water was lost from the canal when lifting, a certain quantity was wasted upon each descent; this was the quantity occupying the space between the closed trough and aqueduct gates, which was carried through a pipe into the pit below. Although the greater part of the energy required to operate the lift was derived from the weight of the water in the troughs, a small volume, about one-twelfth, had to be furnished by hydraulic pressure which was produced by a steam-engine and pump.

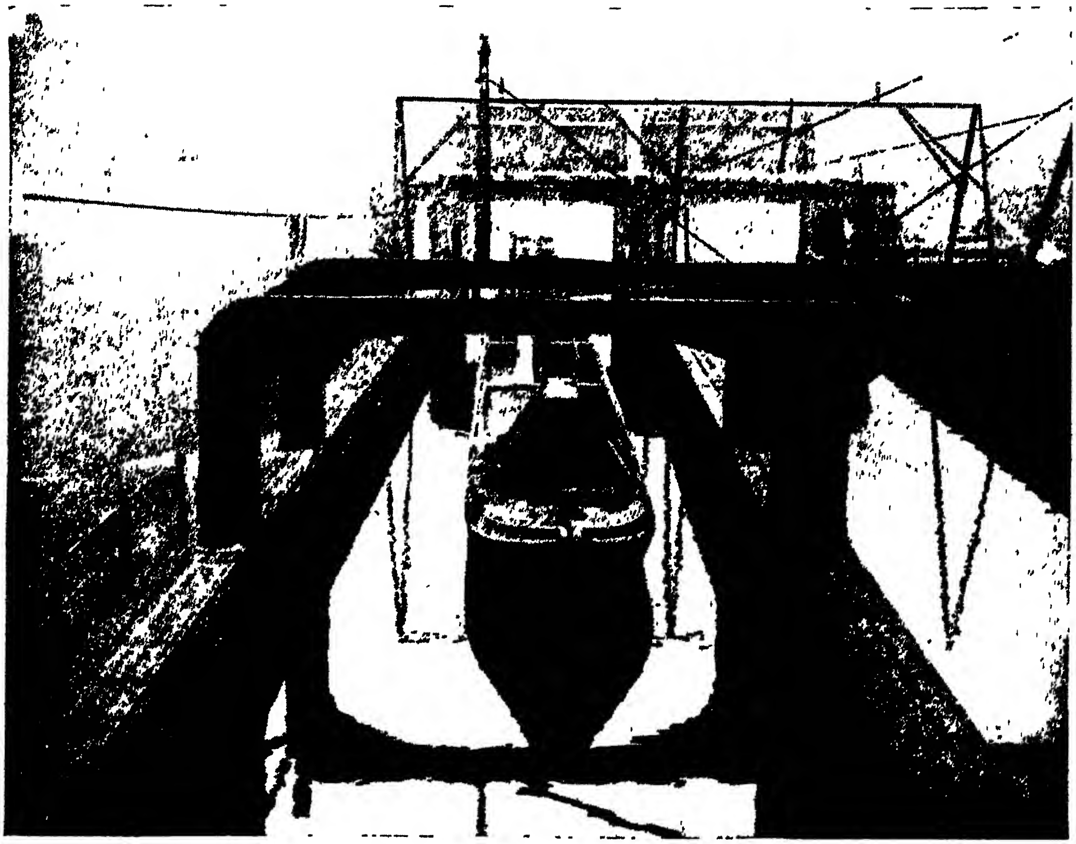
For some ten years the hydraulic system worked uneventfully and satisfactorily, except for the bursting of one of the presses. Then signs of the wear and tear imposed began to become manifest. This depreciation was accentuated by the discovery of the fact that the water, which was being drawn from the canal and with which the hydraulic presses were charged, was somewhat heavily impregnated with chemicals, which set up acute electrolytic action between the copper and iron entering into the construction of the rams. Many expedients were adopted to arrest this action, but no appreciable benefits were observed until the use of the canal water was abandoned and a condensing plant was laid down.



THE WINDING GEAR OF THE ANDERTON BOAT LIFT

At the top of the lift a strikingly simple winding gear has been erected, to which the power from a 30-horse-power electric motor is delivered through shafting, worm and bevel-wheels. All the teeth are helical to eliminate noise and back-lash.

This first material overhaul of the plant was notable for another important development—the introduction of electricity at the lift. It was a modest commencement, entailing the installation of a dynamo and a battery for lighting the lift and workshops, as well as furnishing power for some



THE APPROACH TO THE LIFT FROM THE TRENT AND MERSEY CANAL.
The upper-level connexion between the waterway and the caissons is by an aqueduct divided into two distinct channels. Electrically operated gates control admission to the lift.

warehouses and cranes on the adjoining wharves. At the same time advantage was taken of this power-supply facility to convert the aqueduct and other gates to electrical operation, bringing about the first reduction in labour. The three men hitherto maintained in constant attendance at the gates were no longer required.

A new lease of life was given to the hydraulic system, which prevailed until 1902. It was then found that the steam-boilers, which had been in constant service since 1876, had reached the limit of useful—or, rather, safe—life. Again the situation had to be closely investigated, and this gave rise to the question as to whether it would be more advantageous to renew the boilers or to scrap the steam in favour of electric pumping-plant, the local power-supply company furnishing the power. Careful consideration of the problem resulted in the alternative meeting with favour, and forthwith the electrification of the lift may be said to have been taken in hand, although this represented only a small contribution to the complete problem. The installation of electric motors and pumps, although only for the operation of the auxiliary machinery, proved to be cheaper and more satisfactory than the original steam-power.

Unfortunately, the advantages reaped on the one hand were more than off-set in another direction. The precept concerning the inadvisability of putting a new patch into an old garment was being vindicated. The repair bill was mounting at an inordinately rapid rate; increasing difficulty was being experienced in keeping the rams and the hydraulic pipes water-tight; while

the lift, as a whole, demanded drastic overhaul to render it thoroughly safe.

The chief engineer and general manager to the Weaver Navigation Trustees, Colonel J. A. Saner, M.Inst.C.E., after a thorough and minute examination of the whole fabric and its mechanism, presented a report in which he advocated the total abandonment of the hydraulic system and its supersession by electricity, combined with the reconstruction of the apparatus so far as the conditions of the site would permit. He would have preferred the elaboration of the project and its execution upon a new site, more in accordance with modern principles, but this was regarded as impossible, although it would have been easier and possibly cheaper in the long run. The engineer was necessarily compelled to comply with the conditions which existed, and these in turn precipitated three other acute problems. In the first place, there could be no interference with traffic. Secondly, there must be greater accessibility to all parts for repairs, as far as practicable, because complete renewal was out of the question; and thirdly, the reduction of the cost of the work to the minimum, compatible with the requirements of complete safety, was indispensable.

Possibly the questions of traffic interference and accessibility on account of repairs were the most conspicuous factors in the case. Some experience relating to the expense pertaining to the latter had been gathered from the frequency with which it had become necessary to attend to the

BOAT LEAVING THE LIFT AT THE LOWER LEVEL

When the caisson has completed its descent, the end of the trough in which the craft is floating is opened, thus providing free communication with the river Weaver.

hydraulic rams. Every time these were taken in hand traffic had to be stopped. Accordingly, in order to reduce business disturbance to the minimum, repairs had been carried out as far as practicable on Sundays, when traffic was at zero; but the labour charges upon that day were always 100 per cent. heavier. In so far as traffic interference from the change-over to electricity was concerned, Col. Saner undertook, if his idea were adopted, to ask for not more than three stoppages of the lift at different periods, not exceeding fourteen days in each instance—forty-two days in all. His scheme also indicated how future repairs might be carried out with the minimum interruption of business, because he proposed to sling the troughs or caissons from the top, instead of supporting them on rams, and in such a way as to be independent of one another. A fault in one lift would not necessarily bring the whole machine to a dead stop until the defect had been remedied.

A Well-Kept Schedule

His project was adopted. Although some of the work was relatively of a heavy but more essentially of a delicate nature, it was completed in accordance with the engineer's schedule; the total stoppage of traffic was, in fact, for only thirty-eight days.

As one part of his scheme involved renovation of the structure to such a point as to render it perfectly safe, the means whereby this end was attained is worthy of mention. He decided to convert the bottom or well of the lift into a dry dock, which was done by the insertion of an inverted arch to form the bottom of the basin. This was not only an advantage from the working point of view, but also served to extend a support for the side walls upon which rested the upper structure, representing a dead load of about 1,676 tons.

This dock measures some 80 feet in length by 39 feet in width, and the first stoppage of traffic was made to permit the subaqueous part of the scheme to be completed. A few weeks later the second stop was imposed to allow the new river gates to be put in; similar arrangements were made to permit the work to be carried through to scheduled time.

The remaining sections of the undertaking were now put in hand, but these did not impede the working of the lift in any way. These included the strengthening of the superstructure and its modification to meet the new conditions incidental to electric working. The electric drive was completed in two sections; in other words, the lifts were completed one at a time.

A Striking Pulley System

The new system is interesting because of its simplicity. Above the top of the lift, over the space receiving the troughs at the upper level and forming a roof as it were, a pulley system with its drive has been mounted. The new principle of operation, elaborated by Colonel Saner, depends on two equal weights counterbalancing each other; the motive power is applied to turn the pulley through worm reducing gear and double helical gearing, the weight of which is distributed over a number of ropes. There are thirty-six pulley-wheels, each 72 inches in diameter, to each caisson, set out in two rows of eighteen each, alongside and above each trough.

How the Pulleys Work

Each row of pulley-wheels is arranged in two end groups of five each and two inner groups of four each—eighteen in all. A 30-horse-power electric motor, with tramway controller, resistance automatic brake, and other auxiliaries, running at 750 revolutions per minute, has this speed reduced to 18 revolutions per minute by means of an enclosed worm and wheel. The worm-wheel actuates a longitudinal shaft transmitting the power to two short transverse shafts, making 12 revolutions per minute, spaced equidistantly from the

centre and each end of the pulleys. By means of bevel-wheels the worm-wheel rotates two longitudinal shafts, each 70 feet long, extending the full length of the structure, and fitted with pinions engaging with each pulley. Through this gearing the speed is reduced to 3 revolutions per minute, and as the pinions are 12 inches in diameter and the pulley-wheels 72 inches in diameter, there is a further speed reduction whereby the main pulleys make only one revolution in two minutes. It will be seen that by this arrangement each pulley-wheel is directly geared to the shaft, and as all the teeth are helical there is an entire absence of noise and back-lash. Furthermore, the disposition of the cross-shafts ensures the simultaneous movement of the pulleys by equalizing the torsion on the main shafting.

The Work Completed

The overhead work, preparatory to the actual conversion, was somewhat heavy, involving the placing of girders weighing 15 tons, but this was done without interference with the operation of the lift. When all was ready for the final touches, demanding the stopping of the lift, the third interference with traffic took place. The channel-bars were then promptly attached to each side of No. 1 caisson, ropes made fast, the hydraulic ram-head removed, and other incidentals completed, including certain repairs of a general order. Within fourteen days the first caisson was ready for its initial movement under electric power. When the current was switched on it moved without the slightest hitch.

Directly the first caisson was reopened for traffic, work was concentrated upon the fellow trough, and a few weeks later its conversion was completed. Although the caissons have been slightly modified, their weight remains virtually unaltered, since the attachment of the channel-bars and other incidentals has been off-set by the detachment of the cast-iron ram-head incidental to the hydraulic system.

The weight of each caisson, with its load of water, is 252 tons—the inclusion of a boat makes no difference, because the craft with its cargo displaces an equal weight of water, as was previously pointed out—to counterbalance which 252 tons of cast-iron, divided into thirty-six groups of 7 tons each, are distributed equally on each side. Each group is suspended by an independent rope, which passes over a 72-inch pulley, so that, whatever the stretch of the rope may be, the strain imposed upon the latter can never be in excess of the weight—7 tons plus the friction between the rope and the pulley. Taking into account that practically the whole length of the rope is hanging free when the caisson is elevated to the upper or aqueduct level, any uneven stresses which may have been exerted undergo relief, the rope starting afresh upon each occasion the caisson descends.

A 570-Tons Movement in 5 Minutes

In view of the foregoing it will be realized that the only power required is that necessary to overcome the friction of the pulleys on their bearings, and that incidental to other insignificant sources. Notwithstanding the fact that the total weight which has to be moved is approximately 570 tons, including the wheels, the actual energy demanded to move the caissons does not exceed a Board of Trade unit, while the movement is completed in 5 to 5½ minutes.

The 30-horse-power motor, which may seem to err on the liberal side for such a duty, was installed to permit possible variations in the water-levels of the two caissons, or an unbalanced load exceeding 14 tons. In actual practice, however, this is not required, because the joint at the river end of the caisson is made adjustable to meet fluctuations in level due to drought or floods.

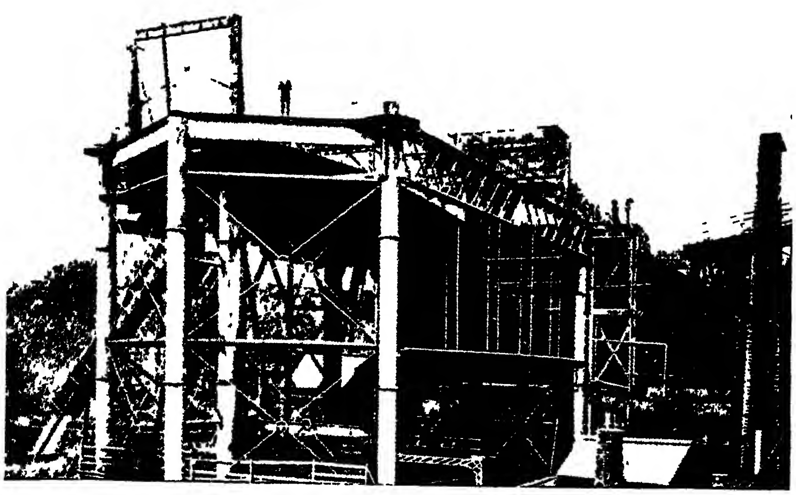
It may be pointed out that the working ropes are merely laid on the pulleys, but the unexpected has not been ignored. A boat might knock out an end gate, and thus

throw a sudden and excessive speed strain upon the ropes and counterweights, tending to precipitate running away; but this contingency is counteracted by the inclusion of an ample number of idle ropes, which coil and uncoil on the larger pulleys.

Another interesting feature of the electrical equipment is the automatic device which has been introduced for lifting the gates in the end of the aqueduct and that of the caisson simultaneously, by means of a single set of gearing. Under the original conditions, each gate was operated separately and was provided with its individual gear. Simultaneous gate movement is accomplished by a locking gear, which is brought into action as the caisson, in rising, approaches the end of its vertical travel. A lug fixed to the aqueduct gate is caused to engage with a trigger attached to a balance-weight and staple. This action brings the staple over a hook fixed to the aqueduct gate and holds it there. When the lifting effort to the gates is applied by the 5-horse-power motor in the overhead control-house, both gates are lifted together, so that a clear passage between the caisson and the aqueduct is established. When the gates are lowered the engaging hook, locking both gates together, falls by gravity, and so releases the staple, the counterweight of which then tumbles clear. There is no danger of any damage being inflicted from the hook failing to clear by gravity, because the lug on the aqueduct gate will cause it to fall as the caisson begins to move.

Electrical operation has proved superior to the former system of hydraulic operation in every respect. Two men suffice to carry out the essential tasks, one man above and the other below, although a third attendant is retained for emergency.

Some idea of the work of the lift may be gathered from the record for a recent year. During twelve months the lift made 14,302 strokes, up or down, passing 16,797 boats from the canal to the river or in the opposite direction; 213,771 tons of freight were carried, for an average consumption of electricity per stroke ranging from ·54 to ·9 of a Board of Trade unit. The circumstance that the lift has been operating with complete success, and without a single mishap, testifies to the excellence of the scheme as evolved by the engineer, and the efficiency of the principle of electrical working adopted.



THE ANDERTON BOAT LIFT BEFORE ELECTRIFICATION

The orginal design provided for the oscillating vertical movement of the two troughs by hydraulic rams By comparing this illustration with that on page 70, the change wrought by electrification may be realized.

HURLING DEFIANCE AT THE MOUNTAIN GRADES.
28-wheel, 3,000-volt International General Electric gearless locomotive for hauling passenger trains over the Cascade Mountain division of the Chicago, Milwaukee and St. Paul Railway.

The Electrification of a Transcontinental Railway—I

HOW THE HEAVIEST GRADIENTS OF THE ROCKY AND CASCADE MOUNTAINS HAVE BEEN OVERCOME

WHEN the latest American transcontinental link of steel, the Chicago, Milwaukee and St. Paul Railway,* was completed and brought into regular operation, certain disadvantages speedily asserted themselves. The road had been planned and built in accordance with the most modern principles concerning grade and curvature. Nevertheless, owing to the severely broken and rugged character of the country traversed through the towering mountain ranges, it was found impossible to avoid grades of 1 in 58 and 1 in 50, and curves of 573 feet radius.

To enable the traffic to be handled over the system with the requisite speed and efficiency, mammoth steam locomotives of the Mallet type were acquired. Some of these were monsters of their class, with a draw-bar pull running up to 150,000 lb. As this effort was far in excess of the strength of the couplings of the vehicles, these engines had to be reserved for

* *See* "Building a Transcontinental Railway in Record Time"—"Railway Wonders of the World," pp. 630 and 679.

"helper" service upon the most severe banks. They were attached to the rear of the train and employed in a pushing capacity.

Snow-fall in the Rockies

Grades and sharp curves constituted only two adverse factors. In the winter the snow-fall among the Rocky and Cascade Mountains is so heavy as to overwhelm the line. Such an outlook for passengers is certainly disconcerting, but it is of far greater moment to the company. Furthermore, the low temperatures which rule in these elevated, exposed reaches of the line, constitute a serious anxiety. Steam locomotives are likely to be frozen up—the water in the tenders and feed-pipes being reduced to solid chunks of ice—in which event a hold-up is inevitable, with the additional prospect of relief being impossible until the weather moderates. This self-same enemy, King Frost, is also likely to place his solidifying grip upon the watering-plants at the stations, thereby rendering it impracticable for the panting locomotives to slake their prodigious thirsts.

72° of Frost

Precisely what snow and ice mean was brought home very forcibly to the railway in question during the winter of 1914–15. The mercury of the thermometer commenced to descend into its bulb in the early part of the season. It sank lower and lower, until at last it registered 40 degrees below zero—72 degrees of frost—and tenaciously hovered around this level for a long period. Then it broke slightly, as if heralding a welcome change, but just as the spirits of the sorely harassed railway officials were rising, the mercury, as if in provocation, again shrank into its bulb.

For several weeks winter pursued these exasperating tactics with paralyzing effect. It became almost impossible to move trains by the steam locomotives. Time after time ponderous freight trains, their locomotives struggling up the stiff grades at a mere crawl, came to a dead stop. As it is fatal for a weary man to sink into the snow to sleep, so it is calamitous for a slowly-moving engine to pull up under such conditions. Within a few minutes it becomes absolutely immovable, and the fire has to be hurriedly drawn to ensure the preservation of the boiler-tubes. Upon the Montana division of this railway the officials knew no rest, day and night, while the cold spell lasted.

Engines Frozen

On one occasion, when the thermometer was well below the 40° mark, there were two freight trains stranded on the main line on either side of Three Forks, the important divisional point in the heart of the Rockies. Their engines were dead and cold, although each train of 75 cars was being handled by three powerful locomotives. To aggravate the situation the "Limiteds," travelling in opposite directions, were due at this important station, which is the passing point. The officials were at their wits' end. If the passenger trains should have to pull up and suffer any appreciable delay, their locomotives would most assuredly be frozen. Fortunately this contretemps was avoided, but only just in the nick of time, by pulling the freighters out of the way.

Could the heavy grades, sharp curvature and low winter temperature be defied? This was the problem which presented itself to the railway company. The issue was discussed in all its aspects, and at last it was decided that these hostile influences might be very pronouncedly mitigated by the employment of electric traction. However, the realization of such a solution turned upon another factor. Could adequate power be obtained and supplied over a sufficient distance to enable defiance to be hurled at the blind forces of Nature? At this juncture, Mr. John D. Ryan, the President of the Montana Power Company, came to the assistance of the railway company, and, as recorded elsewhere (*see* the

chapter: "Taming the Falls of the Missouri River"), Mr. Ryan expressed his readiness to supply electric energy to any desired volume. His proposal was finally accepted.

The power issue satisfactorily settled, there arose the electric principle to be adopted. As the outcome of extensive expert advice, it was decided to have the direct current delivered to the locomotive from the line at a pressure of 3,000 volts. This was a distinct innovation, because such a high potential had never previously been exploited in railway service. Doubts were freely expressed in certain technical circles as to whether such high-voltage current could be collected, but these were partly dispelled by the example of another important system, the Butte, Anaconda and Pacific Railway, which was operating its train service upon 2,400-volt direct current.

Direct Current at 3,000 Volts

Another departure from the orthodox, demanded by the company, was the provision of the locomotives with a full guiding truck at each end. Hitherto the practice had been to employ either a single guiding axle at each end, or a four-wheeled leading truck and a two-wheeled trailer. It was also decided that the electrification scheme should be carried out upon a comprehensive basis, and that four steam-engine divisions—a division is a section representing the limits of the engine's run—aggregating 440 miles continuous length, should first be converted, though it was decided to electrify the Cascade Mountain section as well.

Guiding Truck at each End

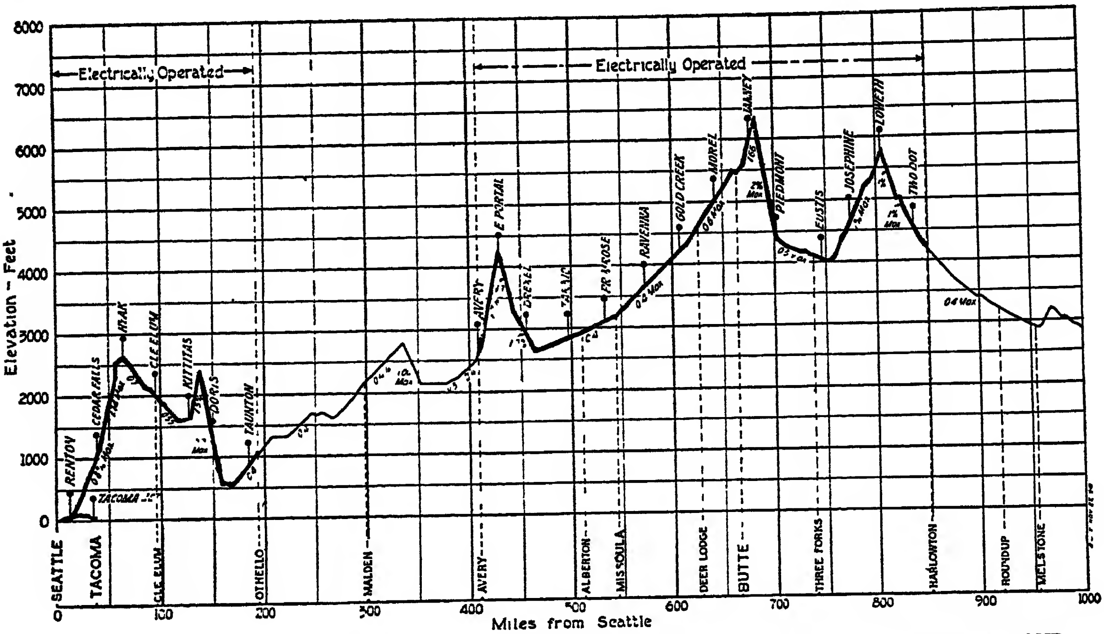
The Rocky Mountain section extends from Harlowton, Montana, on the eastern slopes of the Rockies, to Avery, Idaho, on the western side of the Bitter Root Mountains. Leaving Harlowton, at an altitude of 4,163 feet, there is a rise to Summit at 5,789 feet; the 1,626 feet difference in level is overcome in about 43 miles with a maximum rise of 1 in 91, followed by a descent to Lombard with a maximum grade of 1 in 100 for 52 miles. Clearing the divisional point of Three Forks at the 115th mile-post, there is an easy upward run to Piedmont at the 150th mile lying at 4,359 feet. Now commences the stiffest climb on the westward run, because the line rises 1,993 feet to Donald, the summit level of the railway in the Rockies, in the course of approximately 20 miles; the average rise reads 1 in 58 with reaches of 1 in 50.

Clearing the summit-level the line falls persistently through the succeeding 110 miles to St. Regis at 2,680 feet. This is at the foot of another abrupt rise negotiating the Bitter Root Mountains, the line overcoming 1,589 feet in about 35 miles with a maximum gradient of 1 in 58. The summit is overcome by a tunnel, and is immediately followed by a fall of 1,674 feet in the course of nearly 25 miles; the maximum grade in favour of westbound trains on this side of the range is also 1 in 58.

The "Rockies'" Switchback

Westbound traffic encounters its hardest pull against the collar with the maximum grade of 1 in 50 extending over the 21 miles from Piedmont to Donald. The traffic flowing east is confronted with a steady hard pull of about 25 miles from Avery to the summit of the Bitter Root range, with a maximum rise of 1 in 58, and 49 miles at 1 in 100 to subjugate the western approach to the summit of the Belt Mountains. In addition to the heavy banks there are many sharp curves, the radius of which in some cases is 573 feet; while there are 36 tunnels to be traversed in the course of the 440 miles, the longest being the Pipestone tunnel, 2,580 feet in length, piercing the crown of the Continental Divide near Donald. The line is a single track throughout the whole distance, except at the stations, and where passing tracks are laid; the distance between these points ranges from 1 3 to 9 7 miles.

The daily train service to be handled over this section comprised two "Limiteds" in each direction—the "Columbian" and the "Olympian" respectively—as well as from 590 to 875 tons, while the freighters ran up to 2,500 tons or more. That a supreme test would be imposed upon electric locomotive power was emphasized



CONDENSED PROFILE OF THE ELECTRIFIED DIVISIONS OF THE CHICAGO, MILWAUKEE AND ST PAUL RAILWAY

The distance from Harlowton to Avery is 440 miles, and from Othello to Seattle and Tacoma 211 miles.

a local passenger train plying each way over the 230 miles between Harlowton and Deer Lodge. The freight service moving east and west respectively during the twenty-four hours involved from four to six trains, according to conditions. The traffic bound for the Pacific coast comprised manufactured products; while that *en route* for the east was composed for the most part of grain, lumber, and raw materials from the mines for the various manufacturing interests established between the Great Lakes and the Atlantic seaboard.

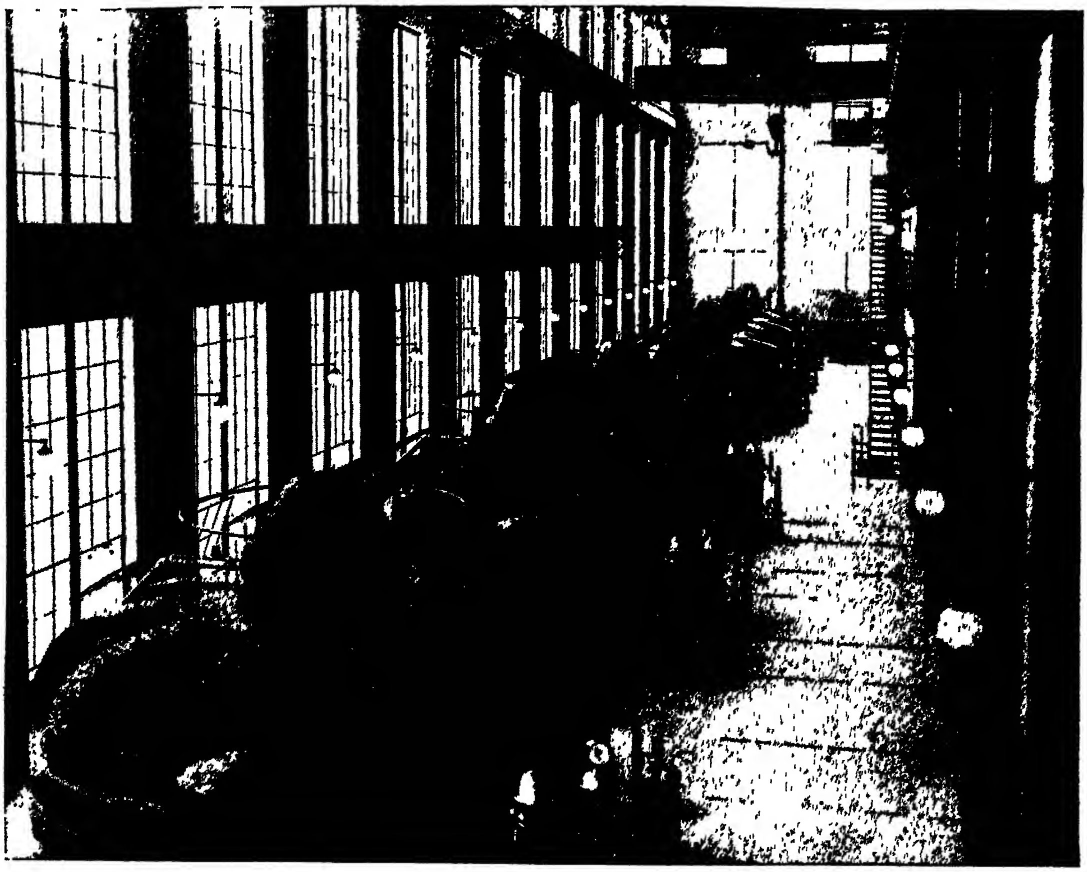
All things considered, this section of a transcontinental railway represented as severe a test for main-line operation by electricity as could be desired. The train loads were necessarily heavy, and the conditions to be fulfilled were certainly exacting. The two express passenger trains, composed of all-steel coaches, varied from eight to twelve cars, with a weight ranging by the dimensions and power of the steam-engines employed. The passenger trains were hauled by huge Mallet engines, double-heading being freely practised, and a third unit was requisitioned as a helper over the heaviest grades when the trains were long and heavily loaded. For the freight service heavy Mallets of the "Mikado" type were specially designed, and here again liberal use of locomotive energy was essential; many of the 80-car freight trains were moved by three of these powerful engines.

The task of converting this great length of line to electricity, as well as the construction of the initial fleet of locomotives, was entrusted to the International General Electric Company, of Schenectady, N.Y. Work was first concentrated upon the section of 115 miles between Three Forks and Deer Lodge, because this is the most difficult portion, involving as it does the

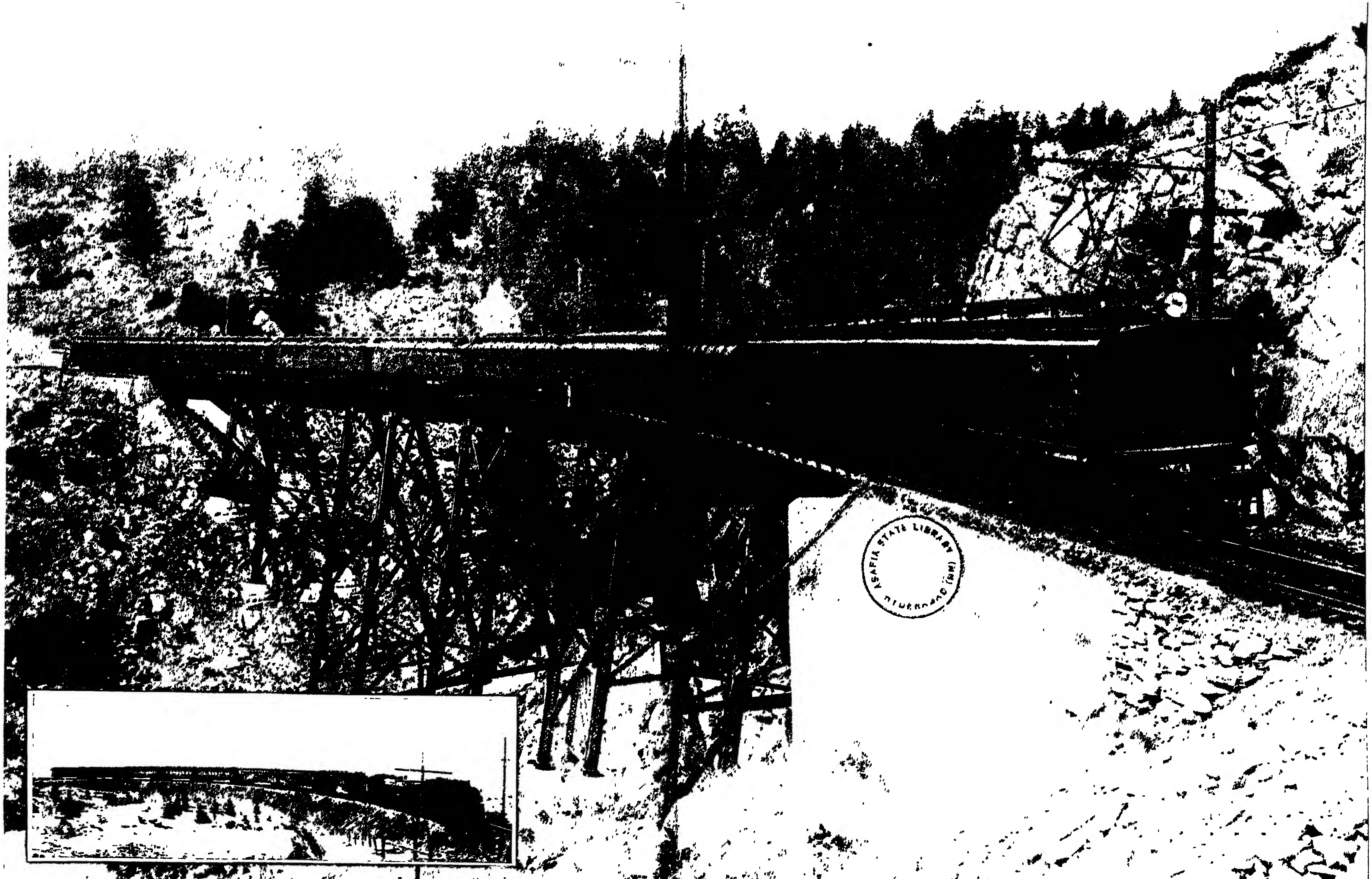
subjugation of the Continental Divide. Thus electric traction was subjected to its first trials under the most severe conditions prevailing upon the whole 440 miles. Electrification of the additional mileage at either end of this section was not deferred until the central division had been completed. The whole of the 440 miles' stretch was taken in hand at the same time, only the section in question received first attention for the reasons stated.

The overhead conductor was adopted. The power is received from the Montana Power Company at seven points at a pressure of 100,000 volts, and is tapped into the railway transmission system. The last-named, of course, extends throughout the 440 miles; the overhead wires are carried on wooden poles. For the most part the transmission system follows the railway line, except at certain places where the line describes a loop to preserve the grade. There the opportunity was presented to strike across the chord of the arc described by the railway, and the advantage taken of the cut-offs enabled an appreciable saving to be effected in the cost of the transmission line.

Between the two extreme points of the electrified zone 14 sub-stations, spaced about 32 miles apart, were built. Each of these is equipped with step-down transformers, motor-generator sets, switch-boards and attendant controlling- and switching-gear. The power company's lines are connected to the transformers at 100,000 volts, and supply the synchronous motors at 2,300 volts. Each of the latter drives two



GENERATING "JUICE" FOR THE TRANSCONTINENTAL ELECTRICS.
The six 10,000-kilowatt generators in the Great Falls power-house of the Montana Power Company.



ELECTRICAL CONQUEST OF THE "ROCKIES."

The "Olympian" of the Chicago, Milwaukee and St. Paul Railway threading the Rocky Mountains. A single International General Electric 3,000-volt, direct-current, 280-ton 4-4-4 + 4-4-4 locomotive hauls the "Limited" over the 1 in 50 grades with ease, and at much higher speed than was possible with the steam locomotives formerly used. Inset shows the "Olympian" under steam conditions, "double-heading" through the mountains.

1,500-volt direct-current generators which are permanently connected in series, thus supplying the 3,000-volt current to the overhead conductor to feed the locomotives. Small direct-current generators, directly connected to each end of the motor-generator shafts, serve to excite separately the fields of both the synchronous motors and the direct-current generators.

The overhead conductor which has been installed is that known as the modified flexible catenary system designed by the General Electric Company. There are two copper wires pliantly suspended side by side from a common steel support or messenger by independent hangers alternately connected to each wire. So far as the conditions permit the conductor is carried on brackets, but at passing tracks, in yards, and where the track alignment is not favourable to this method, cross-span construction is adopted. The conductor is carried on wooden poles throughout.

The Flexible Catenary System

The initial division extending over the 115 miles between Three Forks and Deer Lodge was brought into electrical operation in December, 1915. Four months later the zone had been extended to Harlowton, the eastern end of the electrified mountain section. This brought two adjacent divisions totalling some 220 miles into service, and compressed the previous two steam locomotive divisions into one electric locomotive division. Meantime, the western half was being pushed forward energetically. This was completed and coupled into the eastern end towards the end of the year, so that the opening days of 1917 saw the longest electrified section of main line in the world in full swing.

The Pacific coast electrified zone extending from the ports of Seattle and Tacoma, forming the termini of the railway upon the western seaboard, is a distinct section 211 miles in length, and serves to lift the trains over the Cascade Mountains with their steep grades, sharp curves and tunnels; the eastern end of this division is at Othello. This is a perfectly independent zone; there is a gap of about 200 miles between Othello and Avery, the western extremity of the electrified Rocky Mountains section.

The power for the Pacific and Columbia River division—as the length of railway traversing the Cascade Mountains is officially called — is drawn from the Inter-mountain Power Company, which has command over enormous hydraulic resources in the State of Washington. It is supplied to the railway at four points at a pressure of 110,000 volts. At this pressure it is carried by the railway's transmission line, built along the right of way, and distributed to eight sub-stations, where it is broken down to the 3,000-volt pressure for the overhead conductor by equipment similar to that installed in the corresponding stations upon the Rocky Mountain division.

Pacific and Columbia River Division

The locomotives, of the geared type, probably constitute the most impressive feature of this comprehensive electrification scheme from the popular point of view, because they include the largest, heaviest and most powerful electrics ever built for main-line duty. They were constructed by the General Electric Company, of Schenectady, and the Westinghouse Electric International Company, of East Pittsburg, respectively. Complete details of these giant electric locomotives are given in another chapter.

For the operation of the traffic over the Rocky Mountain division 42 locomotives were procured, 30 being detailed for freight and 12 for passenger traffic respectively. They are almost identical, the only difference being that the gear-ratio of the passenger locomotive is higher than that of its freight-hauling brother, though upon occasions there is free interchange of

service. The gear-ratio of the passenger units permits the haulage of a train, such as a long, heavily-laden "Limited," weighing 800 tons, at a speed of approximately 60 miles an hour on level straight reaches of track. Furthermore, the higher gearing permits the attainment of higher speeds on the grades. The average passenger train can be moved over the ruling grade of 1 in 50, without assistance, by a single electric locomotive. By gearing the freight locomotives speed is reduced, but hauling capacity is increased. Speed is a minor consideration so far as the goods trains are concerned. We find the speed of these locomotives, on all grades up to 1 in 100, reduced to 16 miles an hour, but then the weight coupled to the single locomotive is 2,500 tons. For the negotiation of the maximum grade of 1 in 50 the trailing weight per locomotive is reduced to 1,250 tons, but in actual operation this figure is often exceeded.

Tractive Efforts Compared

The electric locomotive is only some 4 tons heavier than the mammoth Mallet steam locomotive which it has displaced; but, whereas the latter could develop a tractive effort of 76,200 lb., the electric rival develops a tractive force of 136,000 lb. in starting and a running tractive effort of 85,000 lb. Current for the electric locomotives is drawn from the overhead conductor through a pantograph trolley. It is collected by the high-speed passenger and heavy freight locomotives without any sparking or appreciable wear on the overhead conductor. The employment of the 4-wheeled guiding truck at each end of the locomotive, as required by the railway company, has also proved to be equally successful; the unit, despite its immense length and weight, rides virtually as smoothly and as easily, even at the highest speeds, as the Pullman coaches to which it is coupled. Finally, it may be mentioned, regenerative braking constitutes another conspicuous feature; the long descending grades are particularly favourable for the accretion to the utmost degree of all the benefits incidental thereto.

King Frost Holds Up the Traffic

Electric operation had scarcely got into its stride upon the initial division between Deer Lodge and Three Forks when one of the many advantages anticipated from the conversion dramatically asserted itself. Winter had gripped the railways of the North American continent, and the abnormally low temperature of 45 degrees below zero was ruling. Reports of heavy snow-falls among the Bitter Root Mountains came humming across the telegraph wires to the despair of the officials. Trains were being delayed and held up, while such as were making progress were moving so slowly as to raise grave apprehensions concerning their supplies of fuel and water.

While the conditions were at their worst, news came to the superintendent at the divisional point, Three Forks, that a freight train with three engines attached was blocking the single main track east of the station. The approach of the east-bound "Limited" was also notified at the same moment. The superintendent was hopelessly baffled. He had not a steam locomotive within call. It appeared as if the "Limited" would be held up for an indefinite period when it ran into the station. Suddenly the distracted superintendent bethought himself of the electric locomotive. At that time the zone had not been opened east of the divisional point, but the section of the overhead conductor was completed to a point beyond that where the goods train had become stalled. He sought the engineer in charge of construction, and inquired if he could give him any assistance by taking out an electric locomotive and hauling in the stranded freighter, to enable the main line to be cleared for the express.

The engineer, realizing the golden opportunity to demonstrate to the staff just

TRANSMITTING THE ELECTRIC ENERGY A DISTANCE OF 102 MILES AT 110,000 VOLTS TO THE TRANSCONTINENTAL.

Continuous service constitutes the most striking phase of this great railway electrification development, and the Montana Power Company made special arrangements to prevent any possible failure in current supply. This photograph shows the "express" transmission line under construction across the Rockies.

what could be accomplished with electric traction, at once intimated his readiness to give first aid. He switched on the current so as to energize the conductor for a distance of nine miles out of the station, and jumped on the locomotive with the superintendent. Within five minutes the engine was searching for the freighter. They speedily discovered it, coupled up, and within a few minutes were crawling homewards. The pace was slow, but this was due to the anxiety of the engineer to keep the freighter intact; while the electric equipment had not been passed through its tests. Before the express had been admitted into the divisional point the derelict freighter had been safely run into a siding and the main line was clear for the "Limited."

The ease with which the electric pulled the heavy train into the siding created a profound impression among the employees present. Engine crews have a deep dread of being caught on the track, miles from any station, with their engine frozen out; the circumstance that the electric was unaffected by the bad weather convinced one and all that this indeed was the locomotive for winter railway operation in the Rockies. Thereafter, whenever the superintendent of Three Forks received intelligence of a freight train becoming stranded through the engine being frozen he did not worry. He simply sought the co-operation of his friend the electrical engineer, and hurried out with an electric locomotive to drag the disabled train home.

Accelerated service and better time-keeping were the two features which most strikingly asserted themselves after electric operation was inaugurated. It was found that the electric locomotive could cover the journey between Piedmont and Donald —21 miles of 1 in 50 grade—in 25 minutes less than had been possible under steam haulage; the actual running-time for this

stretch was cut down from 65 to about 40 minutes. Similarly in the reach from Deer Lodge to Butte, under electric conditions the distance could be covered in 50 minutes as compared with 80 minutes required under steam. In so far as moving freight was concerned, the steam locomotives required from 10 to 12 hours, according to load and weather conditions, to cover the 115 miles between Harlowton and Three Forks; the electric locomotives comfortably completed the run in 7 to 8 hours.

The driving of electric trains is generally regarded as being extremely simple, but what has been narrated will suffice to show that the handling of the electric locomotive calls for just as much skill as the manipulation of its steam consort, that is, if true efficiency is to be recorded, although, of course, there is less physical effort demanded. But the men selected for this duty proved apt pupils and readily assimilated the special and intensified course of instruction which was prepared. They were placed in the hands of three or four of the General Electric Company's expert engineers, passed through a series of lectures, intimate practical conversations at a subdivisional point, and accompanied by the instructors upon the locomotives. Two of the engineers were about a month on the road, operating the trains with the assistance of their pupils, this being adequate for the purpose. The drivers and firemen drawn from the steam locomotives mastered the intricacies of the new electrics with striking rapidity, and speedily revealed themselves as experts in the control of these power giants.

THE "OLYMPIAN" MAKING SPEED THROUGH THE CASCADES.

The train weighs approximately 650 tons, and is hauled by the 265-ton International General Electric gearless locomotive for 211 miles through this tumbled range with its severe grades and sharp curves. The departure from general practice in the design of the forepart of the engine will be observed; the domed front is somewhat reminiscent of the boiler of the superseded steam locomotive.

TWELVE YEARS' PROGRESS IN ELECTRIC POWER GENERATION BY STEAM.
Interior of the power-house of the Interborough Rapid Transit Company, of New York City, showing on the left the ponderous 7,500-horse-power reciprocating engine unit installed in 1904, and at the rear the Westinghouse 70,000-kilowatt turbine.

The Most Powerful Steam Turbo-generator in the World

HOW POWER FOR NEW YORK'S "UNDERGROUND" IS PRODUCED

WHILE the generation of electricity by running and falling water has made immense strides during the past few years, and has stimulated the design and construction of huge and powerful units, it must not be imagined that the practice of harnessing steam to a similar end has suffered neglect; far from it. Enormous advances have also been recorded in this field. It must not be forgotten that hydraulic energy is not always available for the production of the essential current.

When the compound steam turbine, built by the Hon. Sir C. A. Parsons, appeared in 1884 to demonstrate that a new force had arisen for the generation

of electricity, it created a world-wide sensation. It was recognized that here was a prime mover destined to effect a significant advance. The unit was a small one, coupled direct to a dynamo running at 18,000 revolutions and developing 10 horse-power. Not only did this pioneer reveal the possibilities of the new idea but it carried out useful everyday work as well. For many years it remained in constant service, then, having been completely outdistanced in power and economy by later practice, it was withdrawn from duty. However, it did not suffer summary consignment to the scrap-heap but, being of distinct historic import to the mechanical world, was presented to the Science Museum, South Kensington, where it now finds an honourable resting place beside many other equally remarkable links with the wonderful inventive age in which we live.

First Triple Cross-compound Steam Turbine

Within less than twenty years the power of the steam turbine for the generation of electricity was advanced from 10 to 15,000 horse-power. Development, once started, progressed at a rapid rate, and now within approximately thirty years of the appearance of this new and revolutionary force a turbine developing no less than 70,000 kilowatts has been built and placed in regular service. This installation is remarkable for two reasons. Not only is it the most powerful prime mover designed up to this time, but it is also the first triple cross-compound steam turbine to be placed in regular duty, being composed of three elements—one high-pressure, and two low-pressure units, respectively.

The evolution of such a huge and powerful steam machine for the production of electricity was impelled by the demand for power to meet the transportation requirements of New York City. Owing to the success attending the electrically operated tube railways of London, it was decided to provide the American city with similar underground travelling facilities. But the driving of tubes not being practicable, as in the British Metropolis, geological conditions militating against it, a shallow underground line was carried through the solid rock, the roof of the tunnels practically forming the surface of the highways above. The adoption of such a principle involved enormous expense in construction, but the convenience provided, combined with frequent rapid service, made instant appeal to the citizens. So much so, that extensions in all directions have had to be pursued continuously since the initial section was opened.

Power Increase

The provision of new lines and the increasing density of the traffic, naturally imposed increasing demands for power, and, for many years, there has been a spirited race between the railway building and operating departments on the one side, and the electrical administration responsible for the supply of energy upon the other. It appeared impossible for the last-named to keep pace with, let alone forge ahead of, the former. The growth of the power requirements of the Interborough Rapid Transit Company, which is responsible for the operation of these railways, has indeed been extraordinary. In 1904 it brought into service a new power-station planted in 74th Street. This was equipped with nine towering and ponderous 7,500-horse-power reciprocating engines driving direct-current generators rated at 5,000 kilowatts each—45,000 kilowatts for the station. This volume of energy sufficed for a while, inasmuch as the public had to be initiated into the advantages of the rapid underground facilities now afforded.

Within two or three years the public appreciation had been won, and in such a practical manner as to render the power-station totally incapable of satisfying requirements. When the power-producing capacity of the existing station was

reached, but without any abatement in the demand, the company did not embark upon the construction of a new station or the extension of that already doing duty. Enormous strides had been made in the mechanical world; the turbine had asserted its undoubted superiority to the reciprocating engine. Accordingly, four of the original units, which were immense machines, were torn out and in the space they occupied three compound turbines, each of 30,000 kilowatts capacity, were installed. By this step 90,000 kilowatts were substituted for 20,000 kilowatts without any elaborate extensions, and the capacity of the station lifted from 45,000 kilowatts to 115,000 kilowatts, merely by taking advantage of the progress in invention.

No Halt in Developments

The company anticipated that such a step would enable them to rest on their oars for a while, but they were rudely disappointed. The new plant had scarcely been completed when the now greatly augmented capacity of the station was not only wholly absorbed but overtaxed. As a network of lines was under construction, and the existing roads were being extended, the outlook was somewhat disturbing. Careful consideration of the problem led the company to take steps to secure power well above the immediately prospective demands, although upon this point there were some misgivings, which recent experiences tend to indicate were not unwarranted.

Negotiations were opened with the Westinghouse Electric International Company for the construction of a power unit which should excel any that had been contemplated up to that time. The Company responded to the request with the installation rated at 60,000 kilowatts capacity continuously, and 70,000 kilowatts for two hours, thus bringing the total producing capacity of the station up to 185,000 kilowatts.

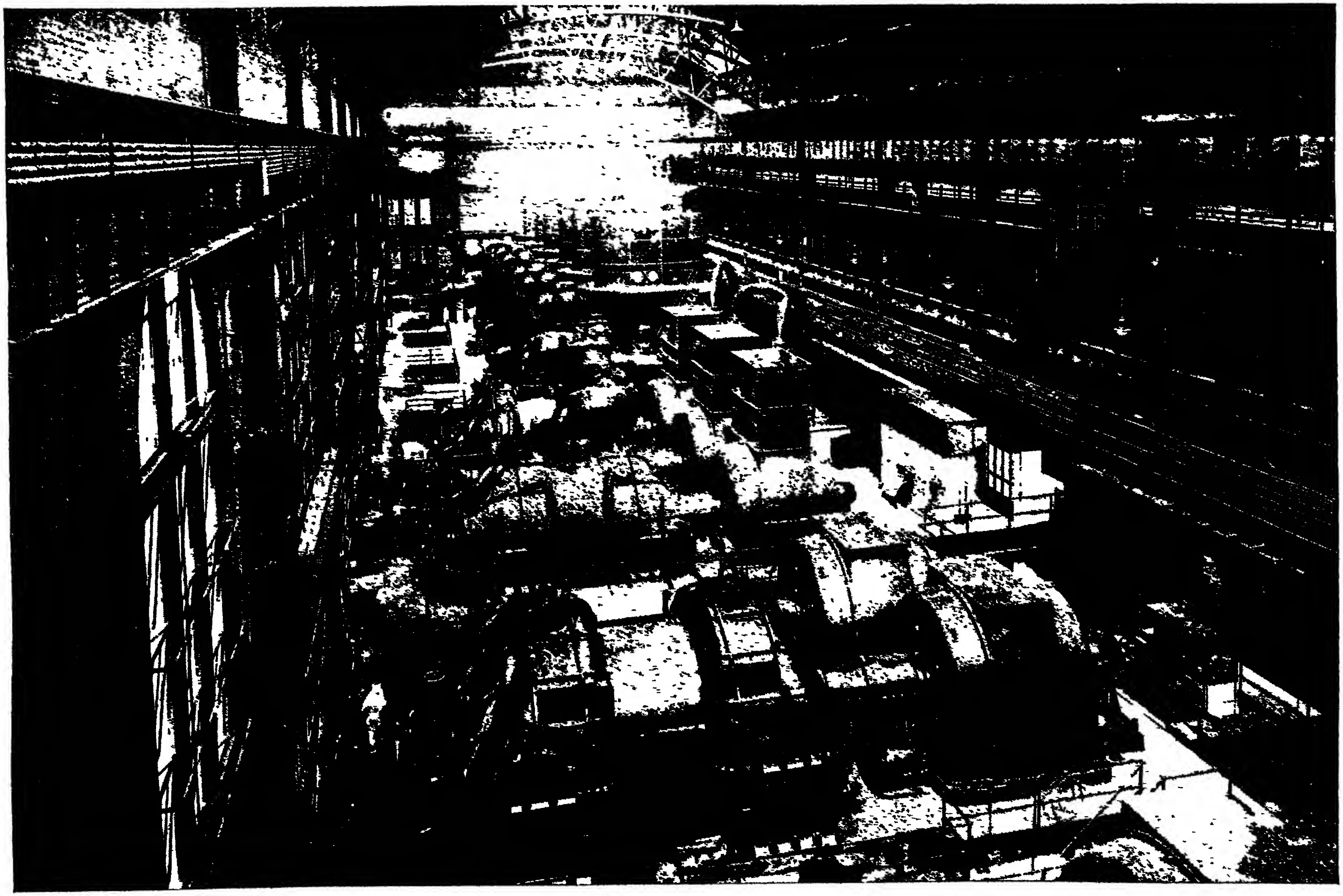
A Giant Unit

The unit in question occupies a floor space 52 feet long by 50 feet wide, and has an over-all height of about 19 feet. The high-pressure unit receives the steam at a gauge pressure of 205 lb., superheated 150° Fahrenheit, and exhausts it into the low-pressure elements at 15 lb. gauge pressure. The two low-pressure turbines are of identical construction, and each receives one-half of the steam exhausted from the high-pressure unit, and exhausts it into the condenser where a vacuum of 29 inches is maintained. All three elements run at 1,500 revolutions per minute, and each is coupled to an electric generator of 20,000 kilowatts continuous rating; 23,500 kilowatts for two hours; and 30,000 kilowatts for half an hour. The generators deliver three-phase 25-cycle, 11,000-volt alternating current.

Although the turbine consists of three separate elements it is regarded nominally as one unit. That is to say, it can be started, synchronized and controlled as if it were but a single machine. At the same time, any one or two of the three elements can be shut down without interfering with the working of the remaining unit or units, so that the high efficiency of a single large turbine is combined with the flexibility which would be forthcoming from three smaller turbines. Furthermore, the three small elements are mechanically much stronger than a single large machine would be; the temperature differences in any cylinder are considerably less while, finally, the arrangement adopted permits the use of commercially common materials, with moderate blade speeds and stresses.

Turbine Types

The turbines are of the pure reaction type without the usual impulse details; this construction is advocated as preferable by the builders owing to the great volumes of steam which are handled. The high-pressure turbine is of the single-flow type, and is made of cast-steel. The low-pressure turbines are of

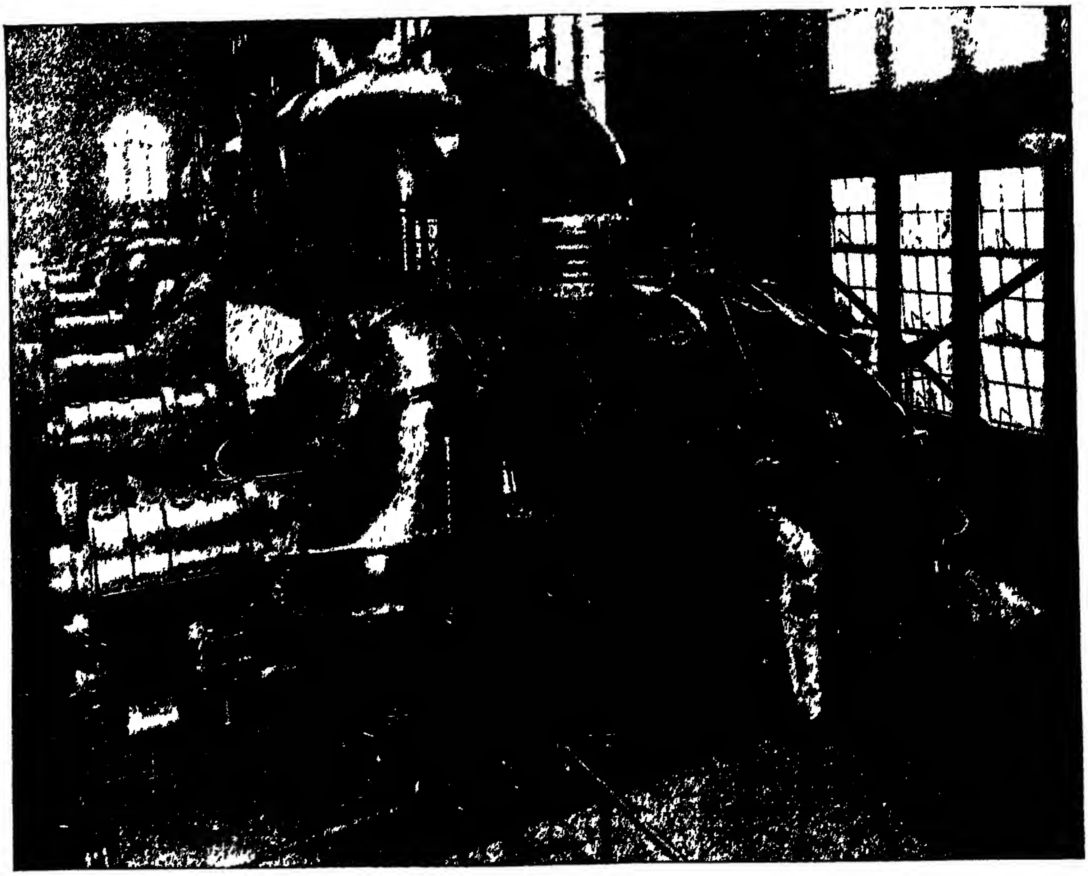


THE STRUGGLE FOR ECONOMICAL POWER PRODUCTION.

General view of the power-house of the Interborough Rapid Transit Company, showing in the foreground one of the three Westinghouse 30,000-kilowatt cross-compound turbo-generators; in the centre new Westinghouse triple-compound 70,000-kilowatt unit; in the background six of the original battery of nine 7,500-horse-power reciprocating engines. The present total output of this station is 185,000 kilowatts.

the semi-double flow type; that is, the steam enters near the centre of the turbine to flow as a whole through a portion of the blading, and then divides into two streams, each of which flows through a separate section into the condenser. As the low-pressure turbines must be able to act as high-pressure turbines in the event of the unit designed for that purpose being shut down, they must be able to receive high-pressure steam. Consequently the central portions of the low-pressure turbines are made of cast-steel also. All three rotors are fitted with Kingsbury thrust bearings to avoid axial movement.

The generators are connected to the bus-bars in such a manner that any combination of them can be operated in parallel. In practice, however, all three are brought up to speed together, and synchronized through a single oil-switch connecting the generator buses to the main bus. Reactance coils are installed between the various buses to limit the amount of current that can flow between the generators. Should a short circuit develop in any of the feeder circuits, or a burn-out occur within a generator, the affected electrical unit is disconnected from the buses by a circuit-breaker without interfering with the operation of the other generators.



THE LARGEST AND MOST POWERFUL STEAM TURBO GENERATOR IN THE WORLD.
The unit, comprising one high- and two low-pressure turbines, covers a floor space 52 feet in length by 50 feet in width, and has an over-all height of 19 feet. Running at full load it consumes 826,000 lb. of steam per hour.

In the synchronization of the generators the field current is first applied to all the generators, and then the throttle valve of the high-pressure turbine is partly opened.

As soon as the high-pressure turbine rotor starts to revolve, it sets the rotors of the low-pressure turbines in motion through the field current. All three then come up to speed together, in correct phase with each other. They are then synchronized with the system, and connected to it by closing a single circuit-breaker.

As may be readily conceived the governing mechanism for such a huge and powerful unit must be of a distinctive character, inasmuch as it is not only called upon to control the unit as a whole, but of each part operating separately. The functions of the governors are interesting.

Functions of the Governors

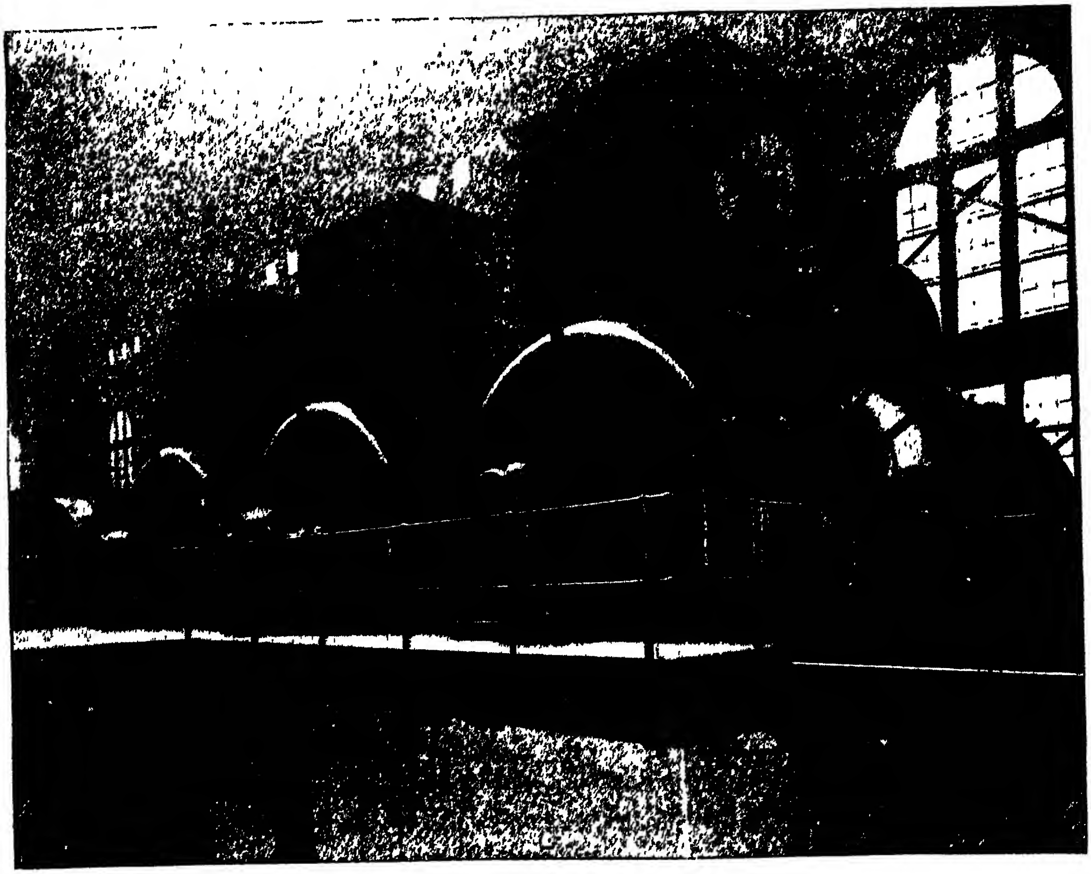
Suppose, for instance, that electrical trouble develops in the circuit of one of the generators of the low-pressure turbines. This generator is immediately disconnected from the bus-bars by the circuit-breaker previously mentioned. The moment the turbine is relieved of its load it naturally endeavours to race, but before its speed has increased by 4 per cent. the steam supply to the high-pressure turbine has been shut off by the governor mechanism. The result of this action is to cause the back-pressure of the high-pressure turbine to rise, and a back-pressure valve opens to permit part of the exhaust from the high-pressure turbine to escape into the atmosphere, the remainder passing into the other low-pressure turbine. Meantime, the first low-pressure turbine, through the default of its generator and the cutting-off of its normal steam supply from the high-pressure turbine, slows down. But when its speed has been decreased to a point 3 per cent. below the normal, the governor admits high-pressure steam, and the turbine continues to run at this reduced speed until the switch-board operator either shuts it down or restores normal conditions.

If it should be the generator connected to the high-pressure turbine which reveals trouble, and has to suffer cutting-out of circuit, the governor shuts off practically the whole of the steam supply to the entire system, only just sufficient being passed to the high-pressure turbine to allow it to maintain its speed without load. The speed of the two low-pressure turbines decreases, but when the frequency has been reduced 3 per cent. the governor admits high-pressure steam direct to the low-pressure turbines, which take up the duty of the high-pressure element. It will be seen that the two low-pressure turbines are now converted into high-pressure turbines. This state of affairs continues until the switch-board operator either restores the running to the normal or shuts down the high-pressure turbine.

Automatic Emergency Stop

Each turbine is also fitted with an emergency stop. This is automatic in its operation, and comes into play in the event of the governing mechanism developing a defect and permitting the turbine to commence to race. It can also be tripped by the switch-board attendant. There is another situation which has to be met. The complete machine may be running under heavily loaded conditions, that is, full normal rating, the whole of its 60,000 kilowatts capacity being required—20,000 kilowatts from each element—when one of the turbines suddenly fails. Immediately the output of the machine is reduced by one-third to 40,000 kilowatts—a serious drop. It can only be met by bringing other generators into operation, but this process occupies a certain amount of time, and the 20,000 missing kilowatts are sorely needed. The interval is bridged over by the remaining two units of the big machine being run up to their emergency, or maximum capacity, namely 30,000 kilowatts, for the governors permit the parts in question to assume this overload. Thus, although the machine has one-third of its mechanism thrown out of action, the normal output of 60,000 kilowatts is preserved. Maintenance of this overloading for thirty

minutes is regarded as adequate to allow other generators to be brought into service to take up the overload of 20,000 kilowatts from the hard-pressed machine.



THE GENERATOR SIDE OF THE MAMMOTH WESTINGHOUSE STEAM TURBINE.

Each element is directly coupled to a 20,000-kilowatt generator. Should one element break down, the remaining two elements can be increased to deliver 30,000 kilowatts, maintaining the normal output of 60,000 kilowatts for the complete unit for 30 minutes, to permit a spare 30,000-kilowatt turbo-generator to be brought into service.

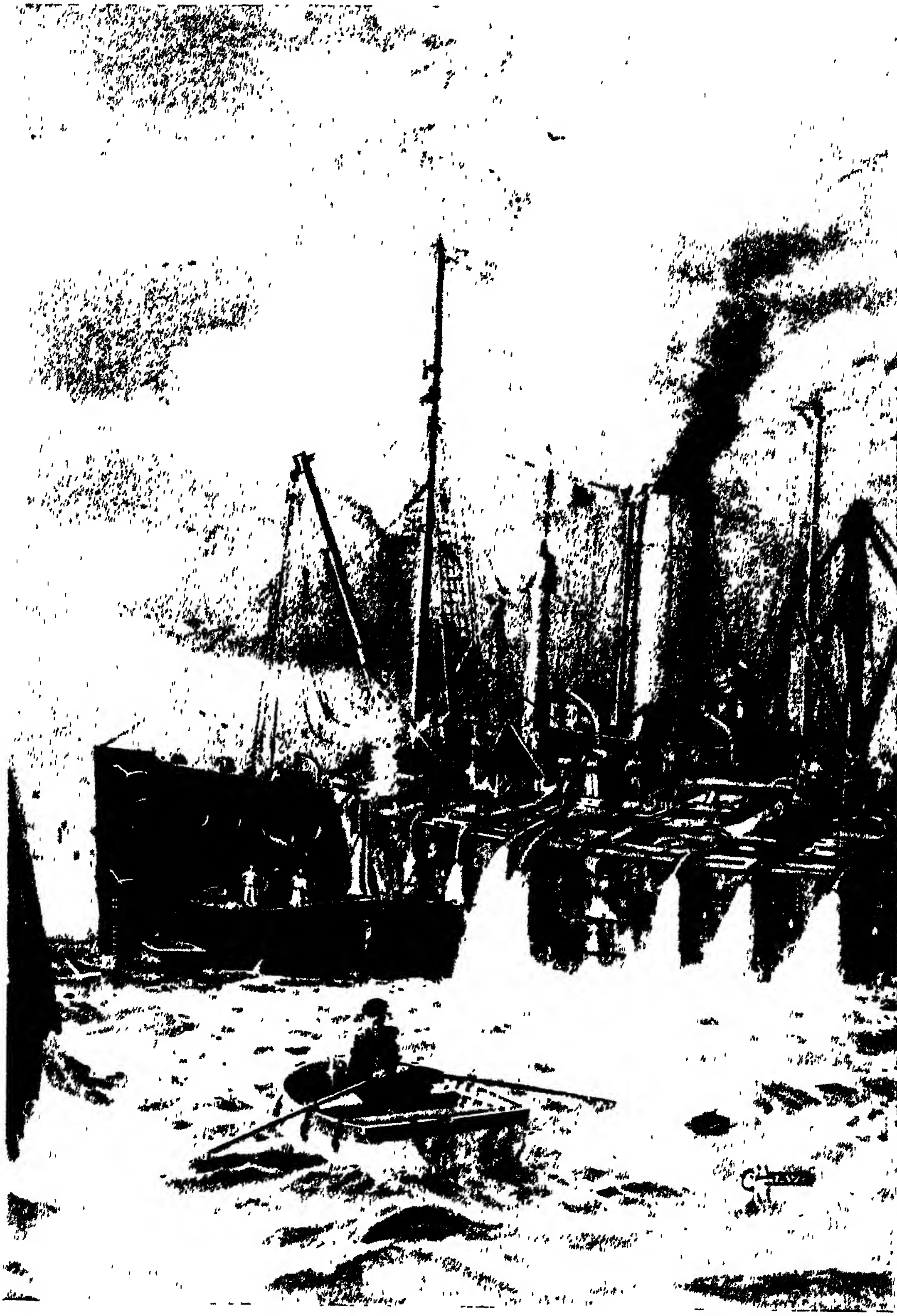
The condenser equipment comprises two surface condensers, each of 25,000 square feet, for each low-pressure turbine—four condensers in all—with an aggregate superficies of 100,000 square feet. For their operation there are four circulating pumps, three Leblanc air-pumps, and four condensate pumps. The whole of the pump installation is turbine-driven, the drive of the air-pumps being direct, while the others are actuated through gearing. The pumping equipment is so arranged that one or more units can be thrown out of service without interfering with the operation of the condenser.

So far as performance is concerned the steam consumption of the entire machine, at its most efficient point, is 10·7 lb. per kilowatt-hour. The high-pressure turbine and one low-pressure turbine, operating together, consume 12 lb. of steam per kilowatt-hour; while one low-pressure turbine, acting independently, requires 14·25 lb. of steam per kilowatt-hour. When running at full load, with the three elements in service, 826,000 lb. of steam are consumed per hour.

The installation of this 70,000-kilowatt generating unit has proved eminently successful, and it is probable, owing to the

CHARING CROSS, THE INTERCHANGE CENTRE OF LONDON'S UNDERGROUND RAILWAY TRAFFIC.

At this station two tubes and the Metropolitan-District meet. To cope with the flood of passengers during the evening rush, 42 trains pass in each direction per hour—a performance unparalleled upon any other railway system in the world.

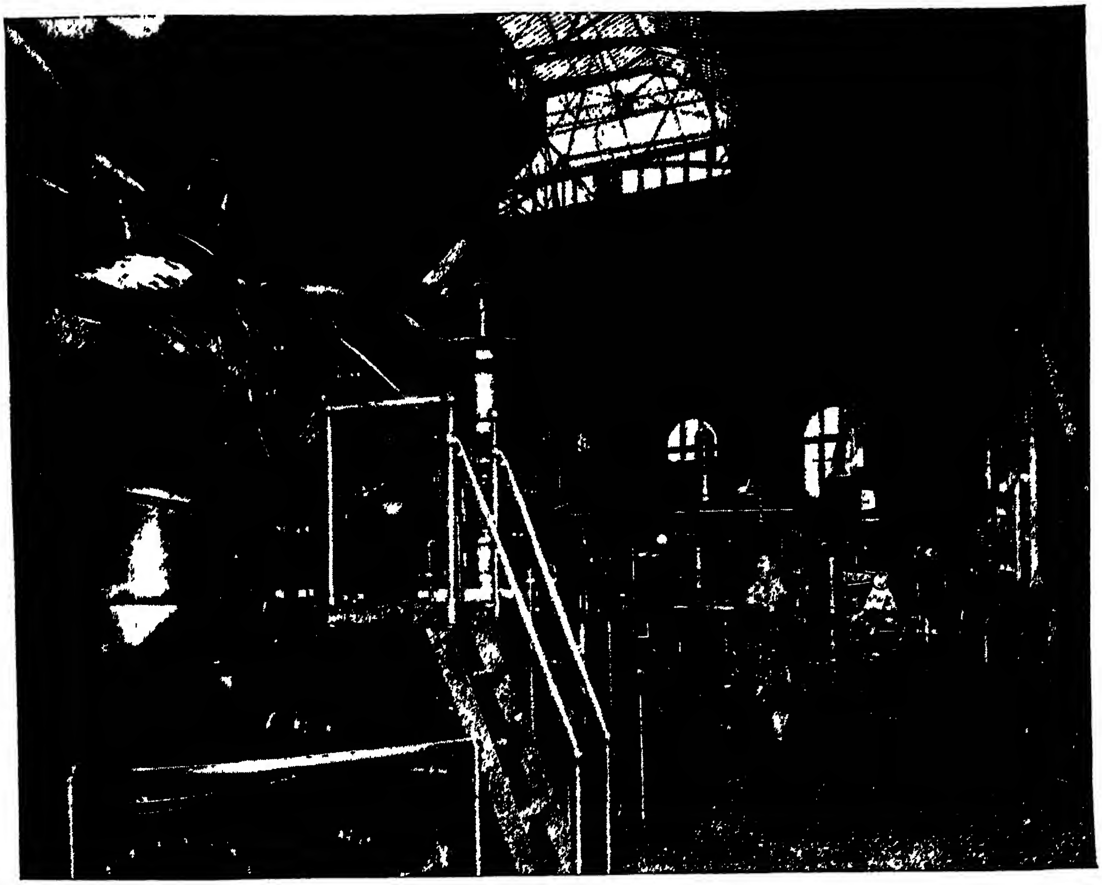


RELEASING A PRISONER OF THE SEA BY ELECTRICITY.

[illegible] motor which will work under water has provided the marine salvage [illegible] weapon. Coupled to pumps, a battery of these motors lowered into the [illegible] speedily [illegible] of water.

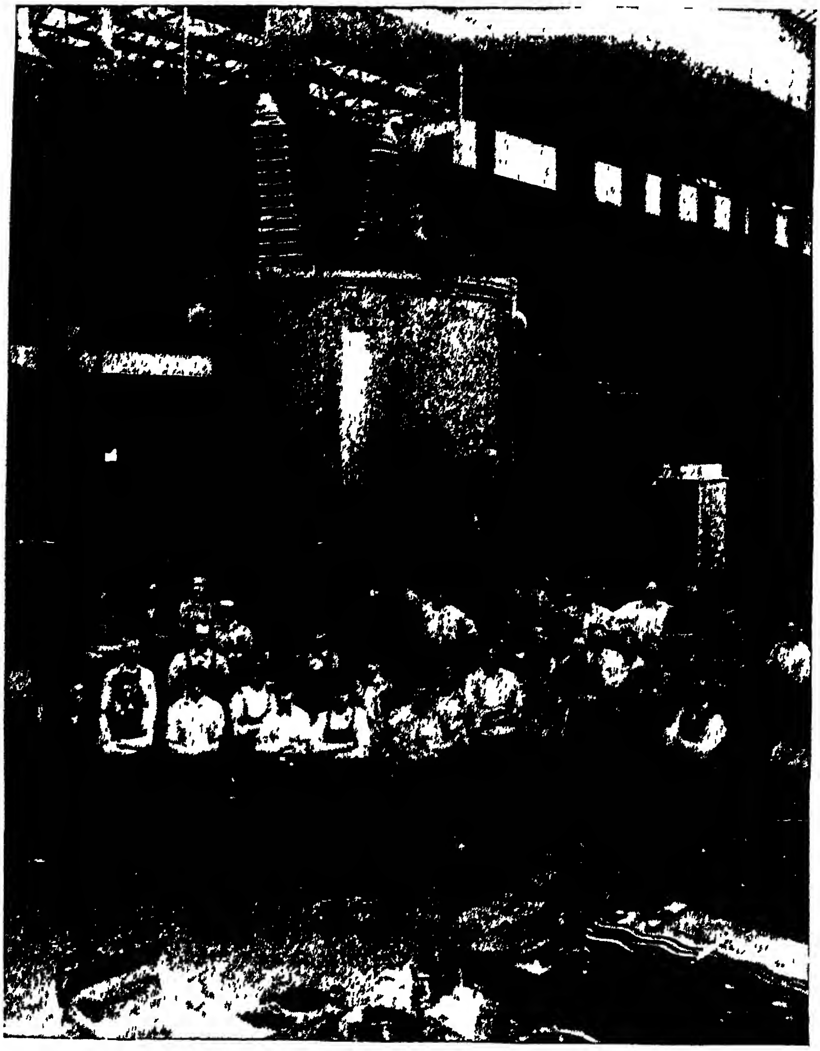
sustained demand for further power, that additional and similarly powerful units will be installed within the not distant future. But the New York installation, while being the first of such enormous power, is not unique. An identical equipment, except in regard to a few minor details, was taken in hand by the Westinghouse Company for the Duquesne Light and Power Company, of Pittsburg. Work upon this plant was in full swing at the moment the United States decided to enter the European war. As this decision rendered it imperative for every available effort to be concentrated upon the furtherance of the nation's welfare, building operations upon the generating unit were suspended.

However, as events proved, it was extremely fortunate for the country that this installation was under way. The American Government decided to produce explosives upon a huge scale, and to lay down a factory for which 100,000 kilowatts of energy were required. Investigations proving that this huge turbo-generator, partially completed, would go a long way towards meeting the situation, the builders were promptly requested to resume their constructional operations, and to push ahead with the work as hard as they could. The response was remarkable. The installation was completed, and, together with the whole of the necessary auxiliaries, was shipped to the new explosives factory within a year, thereby setting up a notable manufacturing record. The erection of the plant in the factory proceeded apace, but



GOVERNOR AND CONTROLLING MECHANISM OF THE 70,000-KILOWATT TURBINE.
This is of a distinctive character, not only controlling the unit as a whole but each element separately.

before the whole of the machinery could be set going the Armistice was signed; the initial run was made with only one element of the turbine, because only sufficient boiler equipment could be finished in time to furnish the necessary head of steam.



THE LARGEST SINGLE-PHASE TRANSFORMER IN THE WORLD

Built by the Westinghouse Electric International Company, it measures 22 feet in height over-all by 10 feet in diameter, and weighs 63 tons, including 18 tons of a special high-grade oil with which it is filled.

For the operation of this giant an elaborate boiler installation was essential, and owing to the abnormal conditions which prevailed at the time the undertaking was assumed, it was found necessary to accept the Stirling type of boiler, giving 1,508 horse-power—the largest unit which could be secured without involving unusual delay in construction. Moreover, owing to the indifferent quality of the coal forthcoming, it was found necessary to instal a bank of twelve instead of ten of these units. These boilers were equipped with underfeed automatic stokers, the width of the furnace to the boiler, which is 27½ feet, allowing the construction of a stoker having fifteen retorts, each with a

combustion rate of 1,000 lb. of coal, but in practice the combustion rate was set down at about 600 lb. The consumption for the whole of the ten boilers, forming the normal working battery, therefore, was 90,000 lb. of coal per hour. Superheaters were installed, and the condition of the steam as it was delivered to the throttle of the turbine was 275 lb. per square inch, with 175° Fahr. of superheat.

In so far as this installation is concerned it may be mentioned that the condensing equipment is somewhat interesting. To fulfil this duty 132,000 gallons of water have to be circulated through the condenser every minute, and this work is performed by three motor-driven centrifugal pumps, each delivering 44,000 gallons a minute. The cooling water is drawn from the adjacent river, and the condensers are placed in a pit, 50 feet 6 inches below the level of the turbines. To connect the turbine exhaust with the condensers four castings, each built up in four sections, of oval cross-section, measuring 15 feet major and 9 feet minor diameter, respectively, and having a total length of 30 feet 6 inches, were necessary. Each of the connexions between the turbine exhausts and the condenser weighs approximately 200,000 lb., while the weight of the condenser fully charged with water, represents a further 400,000 lb., so that the total weight of each condensing unit, ready for duty, is 600,000 lb., or 2,400,000 lb.—more than 1,000 tons—for the complete condensing equipment.

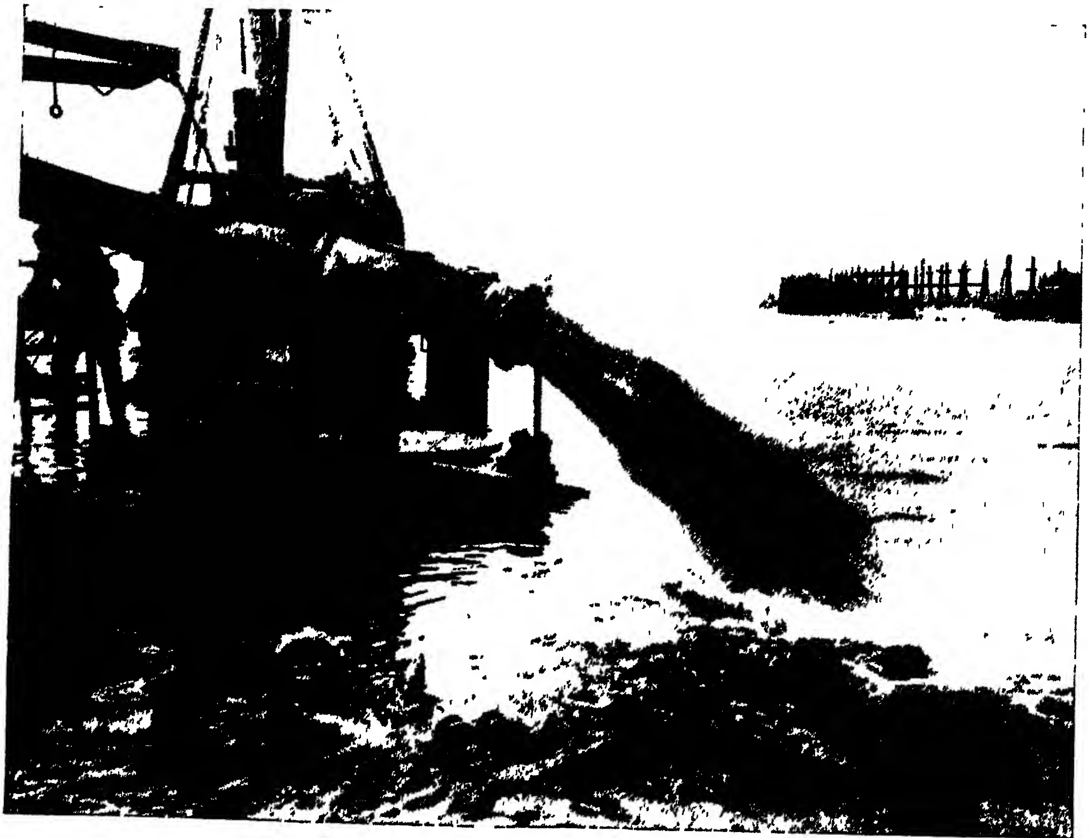
Condensing Apparatus

To ensure sufficient water for the condensers a special canal was built from the river to the power-house. At the entrance floating dams were set up to prevent flotsam and jetsam borne by the river entering the intake. A screen chamber was also established, this being made a part of the front wall of the building. Six screens, having a vertical travel, were installed, and driven by a common shaft; but by the introduction of jaw-clutches any section of the complete screen could be thrown out of service. To prevent the water entering the power-house being commingled with that discharged from the condenser during the p riods when the Tennessee River is in flood, the discharge conduit is covered, and it expels its water into the river at a point below the intake.

Another feature in connexion with this steam giant is worthy of remark, namely the transformers. These were built for service in conjunction with this unit, and were shipped to the Cheswick station of the Duquesne Light Company. There are four of these transformers, each of 23,600 kilo-volt-ampere capacity, and as they are 35 per cent. greater than any single-phase transformer built up to this time, they easily rank as the largest transformers in the world. They are arranged in one bank of three—the fourth acts as a spare. They were designed especially to step-up the output of the three-element 70,000-kilowatt steam turbo-generator from the generating voltage of 11,500 to the 66,000 volts of the transmission. Provision is made so that, when the generating station reaches its ultimate capacity, the transmission voltage may be increased to 132,000 volts. This will be necessary owing to the tremendous amount of energy which will be forthcoming.

Giant Transformers

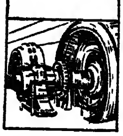
Each of the transformer tanks measures nearly 10 feet in diameter, and is approximately 16 feet in height. With the bushing in place the over-all height is more than 22 feet, measured from the wheel of the truck upon which the tank stands to the tip of the bushings. Each transformer, ready for service, weighs 63 tons, of which 18 tons represent the special high-grade oil with which it is filled.



WRESTING A WRECK FROM THE SEA-BED BY ELECTRICITY.
How the water is ejected by the submersible electric motor-pump from a submerged vessel when the flooded portion has been made water-tight. A 6-inch unit will discharge 750 gallons per minute in a steady stream.

The Triumphs of the Submersible Electric Motor-pump

A BRITISH INVENTION BY WHICH 500 SHIPS WERE SALVAGED



WATER, while being the electrical engineer's friend in certain circumstances, is, in others, his remorseless foe. It is his foe because, when it penetrates to his cables, or the mechanism of his motors and dynamos, it breaks down the insulation, setting up short-circuits and a diversity of other troubles. So he spares no pains to keep water out, a difficult matter indeed when an installation is called upon to work in damp and flooded situations.

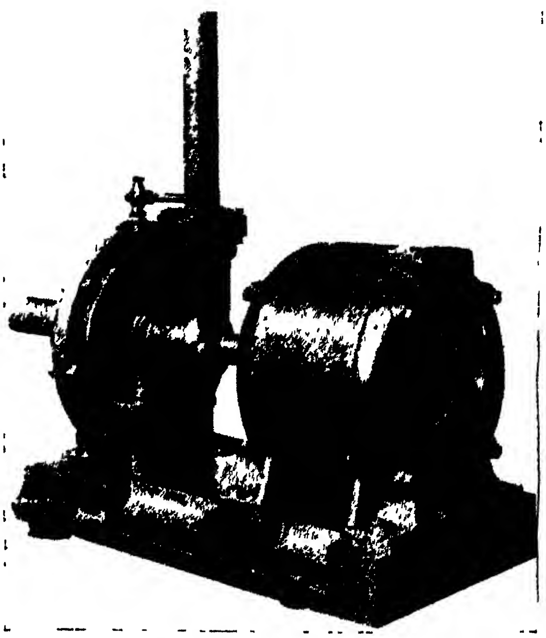
An imaginative and ingenious British engineer, Mr. J. R. Macdonald, cognizant of the unequal character of this incessant struggle against water, conceived a brilliant thought. Why not, he reasoned, turn the foe into a friend? Why not contrive a motor, which, instead of demanding water-tightness, will work efficiently in the fluid? As a matter of fact other minds

had wrestled with a similar idea, but until Macdonald attacked the problem, one and all had discovered the quest too baffling. The inventor in question conducted his investigations along new lines, and, after many months of patient experimenting, succeeded in building a small motor which proved able to work as efficiently under water as upon dry land, and upon which the generally accepted implacable enemy did not exercise the slightest adverse influence.

The initial experiment proved so promising that Macdonald set out to build a larger model. It was still comparatively small, developing only about one horse-power, and in common with all pioneer efforts was relatively crude; but it served to demonstrate the soundness of his principle. Consequently he sought to arouse the practical enthusiasm of those to whom, he reasoned, it ought to make appeal. He contrived a small pump, likewise of special design, which he coupled direct to the motor. To the latter he attached a long length of cable, and to the pump a similar length of small-diameter hose. He lowered this equipment into the river Thames, switched on the current, and instantly a thin stream of water spurted into the air. The motor was running while lying on the muddy bed of the waterway.

Notwithstanding the success of this demonstration Macdonald's achievement failed to arouse more than languid interest. It is doubtful whether he would have pursued the idea any further had it not been for the encouragement of Commodore Sir Frederick W. Young, now the chief of the Admiralty Salvage Section, but at that time salvage engineer-in-chief to the Liverpool Underwriters' Association. This expert recognized at once the great future awaiting the perfection of an electric motor capable of working under water. He urged Macdonald to persevere, and, at a later date, when the inventor came full tilt against the indifference of industry and was disposed to abandon his creation, it was Commodore Young who urged him to continue his efforts.

The inventor accepted the advice tendered, but as the passing months brought no signs of practical development or application of his idea, he became disheartened. He disposed of the whole of his interest in the invention to seek a new outlet for his energies in Canada. Those who had been co-operating with him also lost heart, and so the invention passed into new hands.



THE FIRST SUBMERSIBLE MOTOR-PUMP AS BUILT BY MR J R MACDONALD, THE INVENTOR.
It was about ½ horse-power.

So ended the first era in the history of the submersible pump—a story which, unfortunately, can be paralleled in many another field of inventive activity. However, the new owners of the patents decided to make another determined effort to establish the invention upon the market. But the new campaign for recognition was attended by no more conspicuous success than had been recorded in connexion with the initial effort. The majority of those to whom it was introduced averred that

it suffered from one shortcoming. It required alternating current for its operation, whereas the most promising fields for its utilization were using direct current. To adapt the invention to their specific ranges of service would involve conversion of the current, demanding additional equipment and further capital expenditure, which there was no disposition to incur.

Then came the War. The outlook for those behind the motor became decidedly ominous, although the thought that possibly the conflict might prove a blessing in disguise lingered in their minds. Attempts had been made to secure the practical approval of the Admiralty, but to no material avail. So matters drifted uneventfully until the naval battle in the North Sea in January, 1915. H.M.S. *Lion* received a serious blow in the course of the engagement, and it was the submersible electric motor-pump with which she was equipped that enabled the repairs to be carried out without dry-docking the vessel. The performance of the pump on this occasion induced the Admiralty to investigate the invention more enthusiastically, and numbers were forthwith ordered for the dockyards and naval bases. This order was followed by instructions to the effect that all the vessels of the battle-cruiser squadron were to be fitted with the appliance, and at once.

War Services

The official decision was fortunate, as the Battle of Jutland sensationally proved. When the official reports of that engagement trickled into the Admiralty, it was learned that the enemy had come within an ace of achieving a more remarkable result than he had ever anticipated. Four of our largest, latest, and most expensive fighting units, including H.M.S. *Marlborough* and *Barham*, had narrowly escaped disaster. They had reached port, but it was only the submersible pumps which had kept them afloat.

The Battle of Jutland decided the future of Macdonald's invention after many years of vicissitude. Orders were now given that all the vessels in the navy were to be equipped with the pump. This contract had virtually been completed when the Armistice was signed; H.M.S. *Hood*, the latest capital ship, has no fewer than nineteen of these pumps aboard. To-day this appliance is recognized as being indispensable to the fighting-ship by all the leading nations of the world.

In common with many other striking inventions, the submersible motor-pump is notable because of its simplicity. It is of the induction type, with rotor of the squirrel-cage pattern. The stator laminations are coated with a special varnish and are built up while the varnish is wet. The whole is then submitted to hydraulic pressure to ensure the compression of the core into virtually a solid mass, so that no water can find its way between the laminations. The stator windings are composed of very flexible stranded copper conductors, covered with a special preparation of vulcanized india-rubber, which is resistant to the permeating or disintegrating action of fresh or salt water, or water carrying grease or acid, thereby affording effective protection against short-circuiting. The conductors are wound through tunnels in the stator core which are not further insulated in any way. The coil forming a phase of the winding is in one continuous length, the only junction inside the motor-case being the star-joint. The coils are kept in position by supports coated with vulcanized india-rubber.

Details of the Invention

The ends of the stator windings are brought through a water-tight gland in the motor-case, and are then continued for a distance of 50 feet in a flexible form to terminate in a cable coupling. The conductors themselves are carried in an armoured rubber tube which is securely attached to the motor-frame. This arrangement precludes any strain being imposed

upon the conductors, while it ensures complete flexibility to the lead. Finally, the utilization of the outer armoured hose protects the conductors against damage from chafing and friction caused by any submerged obstacle. The coupling is one of the outstanding features of the apparatus. It comprises a substantial brass case, provided at the tail-end with a stuffing-box. The latter is fitted with a rubber ring which makes a water-tight joint on the cable or conductors as the case may be.

The coupling is in halves—one fitted to the conductors extending from the motor and the other attached to the cable leading from the power supply—drawn together by a robust locking-ring, the joint of which is made by a rubber washer. When the coupling is not in use and is disconnected, covers are provided for protecting the contacts of each section.

Cooling Arrangements

Although regarding water with such an unfriendly eye so far as his motor is concerned, the electrical engineer is confronted with another hostile force against which in the ordinary way he has to use water. This is heat. Naturally the temperature rises as the motor continues working, and special means have to be incorporated to prevent the temperature exceeding a critical level. But with the submersible motor-pump the engineer is relieved of all worries pertaining to temperature, because he deliberately encourages and facilitates the passage of water through his apparatus. When working with this pump, even if it be placed high and dry, the motor-case is at all times kept charged with water, a circulation system having been evolved. Some of the water ejected from the pump through the discharge pipe is permitted to fall into a strainer, where it is filtered, to enter a water passage leading to the inlet to the motor cover. The volume of water admitted is controlled by a simple needle valve. Entering the case the water falls over the windings, and passes into an annular space between the outside of the stator laminations and the case, to leave finally through an outlet, the flow from which is similarly adjusted by a needle valve. Thus a stream of cold water is constantly circulating through the motor, keeping all parts cool. When the motor is working submerged, this circulation is further accentuated by the surrounding water having full access to the whole of the interior.

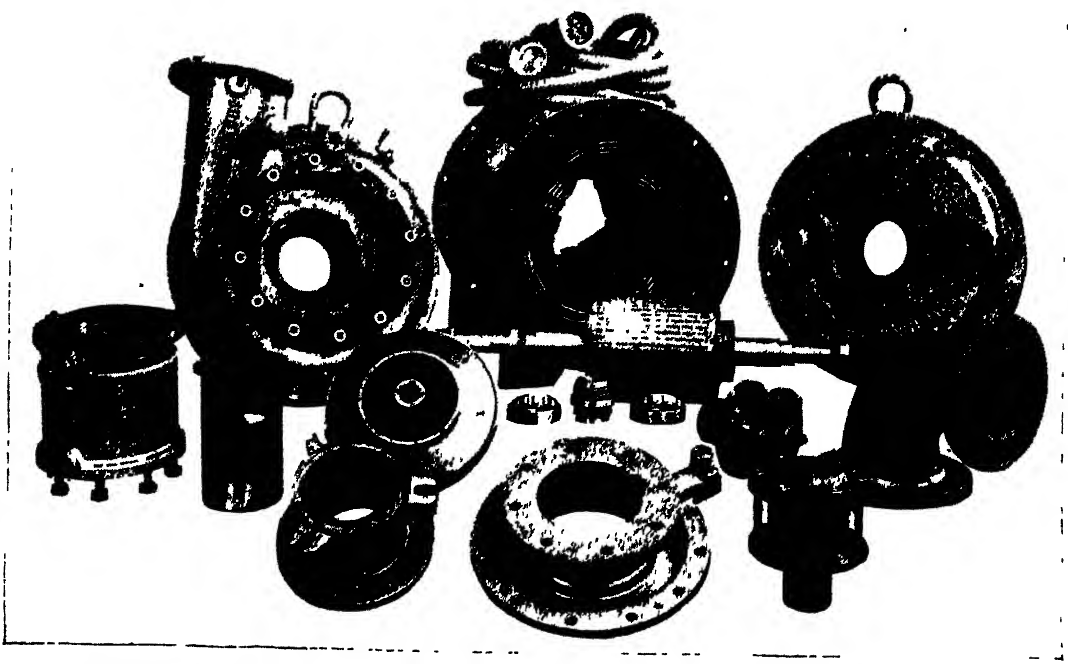
Salvage Work

Although the submersible motor-pump asserted its value in the naval engagements to which reference has been made, it was the salvage work conducted by the Admiralty, under Commodore Sir Frederick W. Young, which revealed its possibilities most emphatically, and spectacularly, from the popular point of view. It may be said to have revolutionized salvage engineering, and is the marine salvor's most handy appliance. Upon the creation of the Admiralty Salvage Section, Commodore Young set to work to acquire an adequate battery of these pumps, and it has been mainly responsible for the reclamation of more than 500 ships of all sorts and descriptions, together with cargoes exceeding in value £50,000,000.

When the Salvage Department of the British Admiralty was organized, all the ships selected for this service were equipped with the submersible pump. For the most part the equipment comprised a number of 8-inch pumps capable of delivering 1,300 gallons of water a minute, coupled to 50-horse-power motors operated by fixed steam-driven alternators, and four, or more, 4-inch pumps with an output of 370 gallons a minute, coupled to 15-horse-power motors worked by portable oil-engine-driven generators; the head in each instance was 75 feet. It was these pumps which, upon the conclusion of hostilities, were employed to raise the block-ships on the Belgian coast, including the

Vindictive and the *Iphigenia*. The raising of the *Vindictive* probably constituted one of the most difficult salvage operations ever essayed. It blocked the fairway into the harbour of Ostend, rendering the navigation of the port extremely difficult. Owing to the manner in which this blockship was sunk, doubts were entertained by the authorities as to the possibility of ever retrieving her intact. In the first instance it was decided to remove the wreck piecemeal, but sentiment, roused by memories of the glorious exploit, led to the public demand for the reclamation of the vessel.

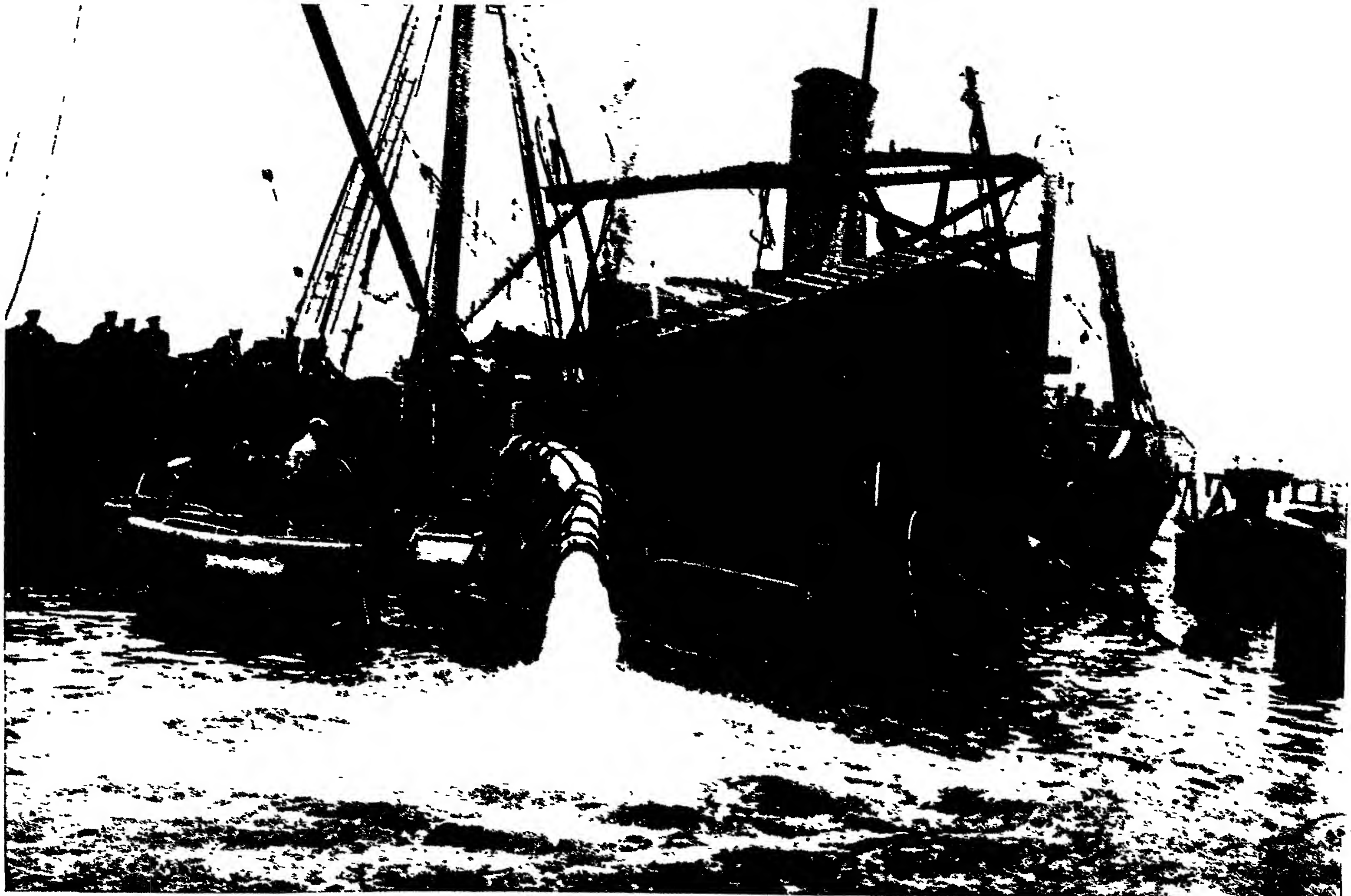
To achieve his purpose the salvage engineer brought a battery of no fewer than twenty-seven submersibles to bear upon the wreck, and, under the water-discharging attack thus delivered, the vessel was raised and moved clear of the channel, to be run aground beside the mole where, at the time of writing, she still reposes. The engineer responsible for this feat has ungrudgingly admitted his success to be due wholly to this appliance, which was the only pump applicable in the exacting circumstances.



A STANDARD 6-INCH SINGLE-STAGE SUBMERSIBLE ELECTRIC MOTOR-PUMP DISSECTED.
At back, stator and its windings with water-tight coupling coiled on top; armature or rotor in front, and centrifugal pump at left.

Stories without number might be related concerning the work of this pump in salvage operations during recent years. The majority of the vessels concerned fell victims to the German submarine depredations, the torpedoes inflicting most grievous injuries. Some of the holes torn in the hulls of the victims upon occasion were of sufficient dimensions to admit a suburban dwelling.

The salvage of the s.s. *Anchoria* was somewhat striking. The engine-room after-bulkhead was damaged to such a degree as to expose No. 4 hold and the engine space to the open sea, while No. 5 hold was also flooded by the water leaking heavily through the bulkhead. The stern of the vessel settled until the after deck was 15 feet under water at low tide, while the bow was canted 45 feet into the air. Such



THE RAISING OF THE *VINDICTIVE.*

The recovery of the famous block-ship from the harbour of Ostend intact is regarded as one of the greatest achievements in marine salvage engineering. It was rendered possible solely by the submersible electric motor-pump, twenty-seven of which were installed for simultaneous operation. This is the only pumping appliance which could have been employed in the exacting circumstances.

an abnormal trim exposed the ship to excessive straining. The sheer strake on either side began to crack near the engine-room after-bulkhead, and, to make matters worse, the ship took a list to port of 15 degrees.

The use of a coffer-dam in No. 5 hold was the obvious expedient, but it would have occupied too much time, and required heavy timber, whereas the only wood available was a limited quantity of 1-inch planking of which the horse-boxes on deck were built.

The Apparently Impossible Achieved

Within three days of reaching the wreck the apparently impossible had been achieved. The engineer lowered one 4-inch and two 8-inch "submersibles"—the laconic colloquial salvage term for these pumps—into No. 5 hold. Then he covered the whole hatch coamings with large hatches contrived from the planking of the horse-boxes, only leaving holes for the passage of the electric cables and the discharge pipes from the pumps. In this manner the after part of the vessel was pumped out, and the ship run on to the beach to permit patches to be placed over her wounds preparatory to towage into port.

Equally remarkable were the recoveries of the steamships *Chiverstone* and *Comrie Castle*. The first-named ran on the rocks off the Island of Skye, ripping open all her bottom plates from her stem back to No. 2 hatch setting-up plating, loosening a large number of rivets in the tank-tops, and allowing holds 1 and 2 to fill. A 12-inch oil-engine-driven pump and a 6-inch submersible were promptly dispatched to the wreck. The larger pump was placed on the maindeck forward and the holds pumped out. The smaller portable motor, with its dynamo for the 6-inch unit, was set up in the engine-room. After the tank-tops had been made nearly tight with plugs of pine and cement, the vessel was got under way for Glasgow, floating forward on the tank-tops, which were leaking rather badly.

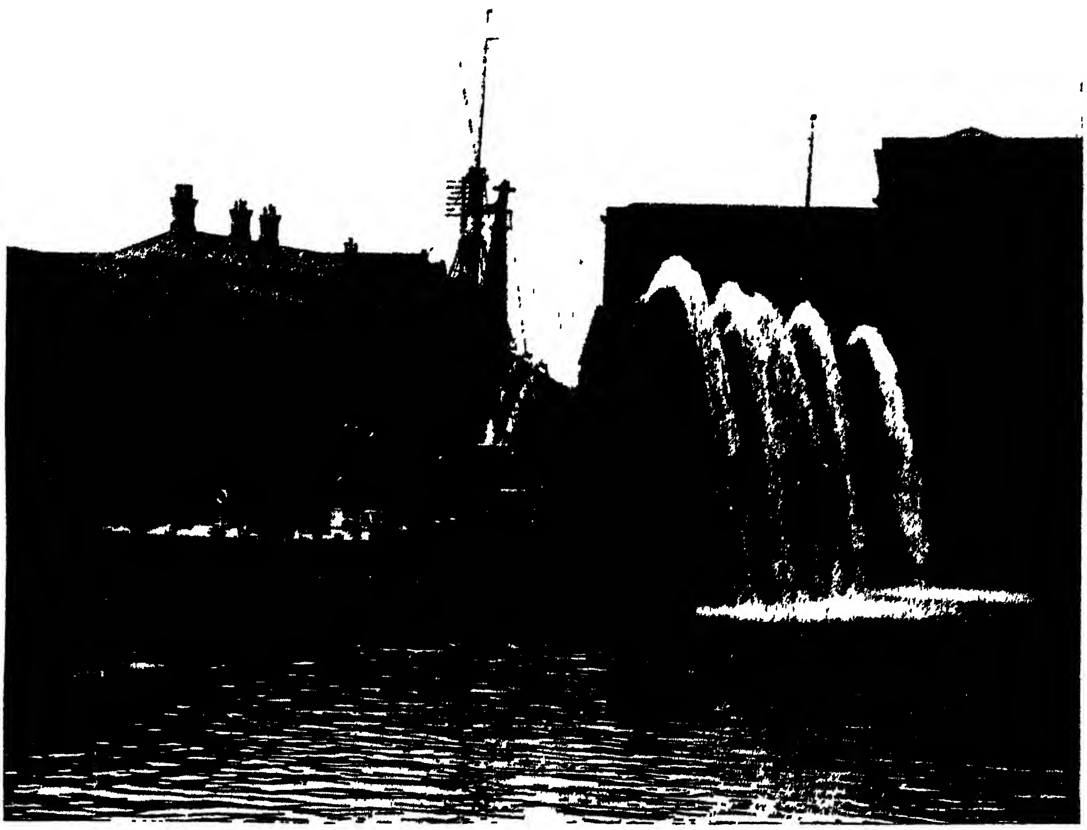
During the run to port heavy weather sprung up. Tumultuous seas crashed aboard, causing the limping ship to tremble from stem to stern, and putting the oil-engine of the 12-inch pump out of action. Dependence now had to be reposed in the single submersible. The electric cable carrying the current from the dynamo rigged up in the engine-room, was reeved from the latter along the deck, and through the hatch into No. 1 hold. For two days and two nights this pump was kept going at full pressure. It did not receive the slightest attention, but had to be intermittently stopped and restarted, although these operations were always conducted from the engine-room.

Vicissitudes of Salvage Work

The work which circumstances imposed upon the submersible in the case of the *Comrie Castle* was more searching. The engine space and No. 4 hold were laid bare, and the only part abaft where buoyancy could be obtained was No. 5 hold, the intervening bulkhead of which was badly damaged. A south-east gale sprang up and drove the helpless vessel on to a sandbank near Selsey Bill. Two portable submersibles were installed aboard with all speed to handle the water leaking through the damaged bulkhead, while ground moorings were also put down to heave off the vessel. These preliminaries occupied some ten days, working each tide, during which the pumps were kept at work.

While salvage was in progress a second south-east gale sprang up. All the attendant craft had to run for shelter to harbour, where they were held for two days. During this spell No. 5 hold was battened down, but the submersibles were kept at work, and succeeded in keeping the incoming water in check, despite the heavy weather. Some idea of the force of the seas which thundered aboard may be gathered from the statement that the starting-gear of the

submersibles, which had been lashed on the maindeck alongside No. 5 hatch, was picked up and washed on to the poop. In this instance the cables and discharge pipes from the pumps were taken through the ship's ventilators. This suffices to indicate the handiness of this appliance, because there were no other pumps presenting such a feature of ready adaptability.



THE PUMPING CAPACITY OF THE SUBMERSIBLE ELECTRIC MOTOR-PUMP.

An interesting test. Five pumps were lowered over the side of the vessel to rest upon the harbour bed and set going. The five fountains of water shown were the immediate result. This pump has a lift, when working submerged, of 75 feet in a single stage. This demonstration conclusively proved its far-reaching value to the marine salvage engineer.

Perhaps the most imposing salvage achievement of the submersibles was that whereby a mammoth ship, carrying a cargo, including metal, valued at £3,000,000 was snatched from the jaws of the sea. This vessel was on her way to Liverpool when she came to grief. The stricken ship, despite the heroic efforts put forth to get her into the Mersey port, settled deeper and deeper by the bow into the water, until her propeller was lifted high into the air. Then, of course, she was absolutely helpless, and slowly foundered. The salvage engineers were promptly on the spot, to find the vessel 30 feet under water at high tide, and virtually flooded from stem to stern, because the bulkheads had not been carried higher than the shelter deck.

This discovery led to the suggestion that if the water could be confined to the damaged hold and the remainder pumped dry, the vessel could be saved. Forthwith the salvage engineer contrived trunks to

continue the bulkheads of the damaged hold from the shelter to the top deck. At the same time the hole in the hull was patched. Unfortunately, the ship had foundered in a badly exposed position, and inclement weather sorely handicapped salvage operations. The engineer then modified his original idea to the extent of trying first to move the wreck closer inshore. Submersibles were accordingly distributed throughout the flooded but undamaged holds to expel the water. As this was accomplished the ship commenced to regain buoyancy, presently swinging clear of the sea-bed. When free and with the pumps still going, she moved inshore for about two miles before she again grounded.

THE GREATEST ACHIEVEMENT OF THE SUBMERSIBLE PUMP

These three units were lowered into the hold of a vessel sunk in 30 feet of water, and remained continuously submerged for three months. By their use the ship with its cargo, valued at £3,000,000, was recovered.

The bulkhead trunks part of the original salvage scheme could now be pursued more favourably, but the idea of patching the hole had to be abandoned, because the waves splintered the temporary wooden dressing as rapidly as it was applied to the wound. Fourteen weeks passed before the engineer deemed it prudent to attempt to make a bold bid for port. The submersibles were again brought into action, and the expulsion of the water proceeded merrily apace, the vessel meanwhile slowly rising until at last she had lifted sufficiently to permit of towage. Port was reached without further mishap. This was the supreme test to which the invention had been subjected. The motor-pumps were left submerged in the holds of the vessel for three months without a single withdrawal. When finally released from duty they were examined, only to be found in as perfect condition as upon the day they were first lowered into position.

One outstanding feature of this pump, which demands remark, is that it can either be lowered into the hold of a submerged vessel to rest firmly upon the bottom, or it can be slung at any point above or under the water. It works with equal efficiency in any position. Furthermore, it can be supplied with energy from any distance.

It is only necessary to attach the main supply cable to the motor lead with the special coupling carried by the pump. When working at single-stage it will pump from a depth of 75 feet; when used above water-level it has a suction lift exceeding 30 feet.

A Unique Record

The following is an extreme instance of the adaptability of this appliance. An outbreak of fire was reported to the captain of a ship carrying a valuable but inflammable cargo. He had two submersibles aboard. He at once ordered them to be slung overboard and set to work pumping water into the hold in which the fire was raging. This was done. and the flooding of the hold speedily extinguished the conflagration. Then the captain gave instructions that the pumps should be hauled aboard and lowered into the flooded hold to pump the water back into the sea.

The pumping capacity of the submersible varies from 80 gallons a minute for the smallest size, equipped with a 2-brake-horse-power electric motor, operating on three-phase current of 50 cycles at 100 volts, to 4,000 gallons a minute in the case of the 14-inch unit fitted with a motor rated at 75-brake-horse-power working on three-phase current at 220 volts. Except in the case of the smallest unit, the single-stage pump will lift the water to a total height of 75 feet, but by attaching a pump of several stages to the one motor, any lift can be satisfactorily overcome.

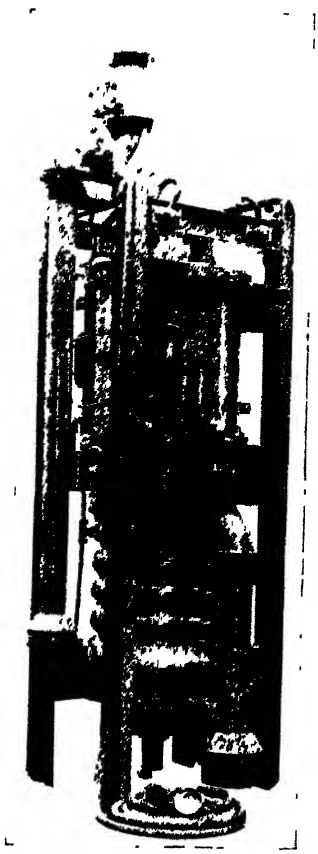
The applications of the pump are by no means restricted to marine service. A large textile manufacturing establishment in the Midlands conceived the idea of utilizing the water inflow to an abandoned coal-mine shaft for its industrial use. This shaft is situated in a wood some distance from the mill, and had not been touched for more than eighteen years. Although it was well charged with water it was also known to contain an accumulation of debris of a varied character. Before coming to a decision the management desired to ascertain the precise daily inflow of water to the shaft. To determine this question it was necessary to reduce the water in the pit to about 160 feet below the ground-level.

The conventional pump was ruled out as useless for the task, and the company, having heard about the service record of the submersible pump, requested the manufacturers—Submersible Motors, Limited—to extend them assistance. Forthwith two 4-inch pumps of this type, each having a capacity of 375 gallons a minute, were dispatched to the old mine-shaft. The delivery side of one pump was coupled to the suction side of the second pump, and in this way the equivalent of a two-stage pump was secured, the total lift being approximately 160 feet.

Services in a Flooded Coal-mine

A timber head-gear was rigged up to permit the pumps to be lowered into the pit, the upper unit being slung at a height of 80 feet, while the second was submerged to a depth of 160 feet. The level of the water was promptly reduced as desired. The inflow being insufficient to meet the requirements of the textile factory, another test was conducted at some more extensive abandoned workings nearer the factory. Here the water had risen to within 11 feet of the surface, and it was decided to reduce its level to 300 feet below ground-level. Four 6-inch pumps of 740 gallons a minute capacity were required for this task to overcome the total lift, the coupling up being carried out as before to reach the 300-foot level. The pumps, when at last lowered into their two respective positions — they were coupled up in pairs—were set going and remained working continuously for five days, by which time they reduced the water-level to the 160-foot level. After a further seven days of continuous pumping

the water was lowered to 275 feet. Instructions were then given to throttle down delivery, and to maintain the water-level in the pit at a constant point to enable the inflow to the shaft to be gauged. This began at 47,000 gallons, but, after three days, it fell to 33,000 gallons an hour. In this instance the submersibles were kept going for thirty-seven days, one set, or pair, working continuously for twenty - four days, on nineteen of which they were in action the round twenty-four hours. During this period of 646 hours they actually lifted 33,623,604 gallons of water from the shaft.



THE SUBMERSIBLE ELECTRIC MOTOR-PUMP IN THE MINE
Latest six-stage model which, with 4-inch discharge, will deliver 300 gallons a minute to a height of 500 feet with motor developing 85 horse-power.

This novel operation was not entirely free from excitement. The withdrawal of the plant from the mine-shaft proved even more difficult than lowering it into position, inasmuch as the lower pumps and pipe-line, while being withdrawn, fouled the decaying brickwork and staging at a depth of 240 feet. Manipulation from the surface failed to clear the gear from its entanglement. The engineer offered a tempting reward to any one of the number of local miners gathered round the shaft, following the operations, who would undertake to descend the shaft in a "bo's'n's-chair" to release the gear. It fell on deaf ears; no man would have anything to do with such an enterprise. The lining of the shaft was in a decrepit condition, the stage was even more precarious, and the slightest vibration might bring the whole fabric tumbling about one's ears while down below.

The engineer was in a quandary. He declined to admit the possibility of losing valuable equipment. If no miner would go down, then he must descend himself. His assistant volunteered to accompany him, and the two disappeared down the yawning shaft to the ominous head-shaking of the miners. It was an eerie sensation, descending that vertical tunnel in a swaying seat at the end of a rope, with the water dripping mournfully from the soddened, crumbling and threatening lining, steering carefully by ugly obstructions, and catching the sounds of the weird thuds of falling masonry striking the dank water below.

Labouring under such conditions at a depth of 240 feet, in the desperate endeavour to free the tackle, was even more nerve-racking, owing to the risk of the slightest jar precipitating the collapse of the staging or an ugly cave-in. With difficulty the gear was at last brought adrift, and the men were hastily hauled to the surface none the worse for their adventure.

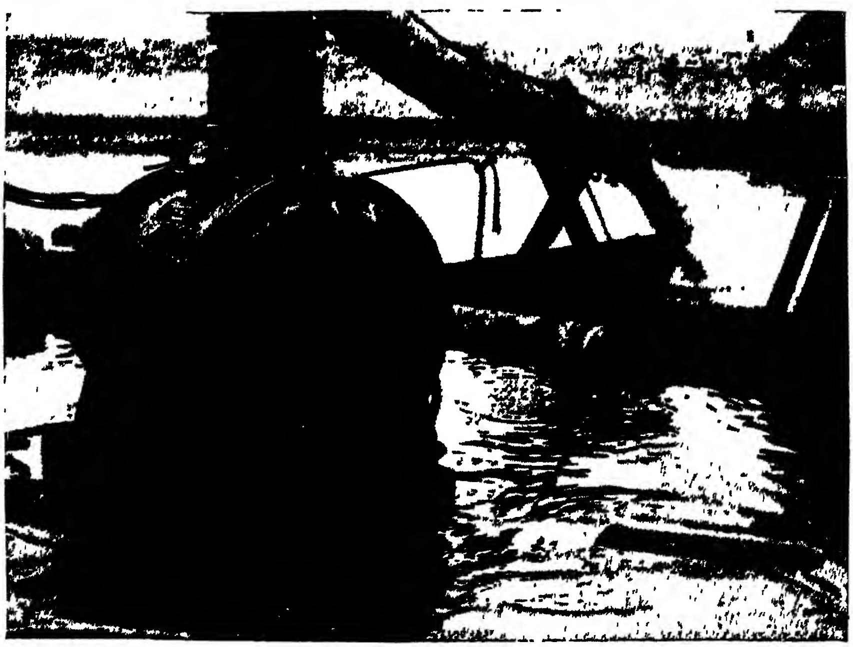
This enterprise served to reveal very convincingly the possibilities of the invention in a peaceful sphere. It proved that the motor-pump could be lowered into the most awkward situations with comparative facility, and could be used successfully where other pumping systems were impracticable or too costly.

The mining world now recognizes the advantages of this British invention, and the submersible pump is being extensively adopted. Numerous installations have been laid down among the devastated mining areas of northern France to reclaim

the mines wrecked by the Germans. It has also been freely adopted by British collieries, as well as in China and Mexico, the installations running up to 300-brake-horse-power with a pumping delivery of 3,000 gallons per minute through a lift of 600 feet.

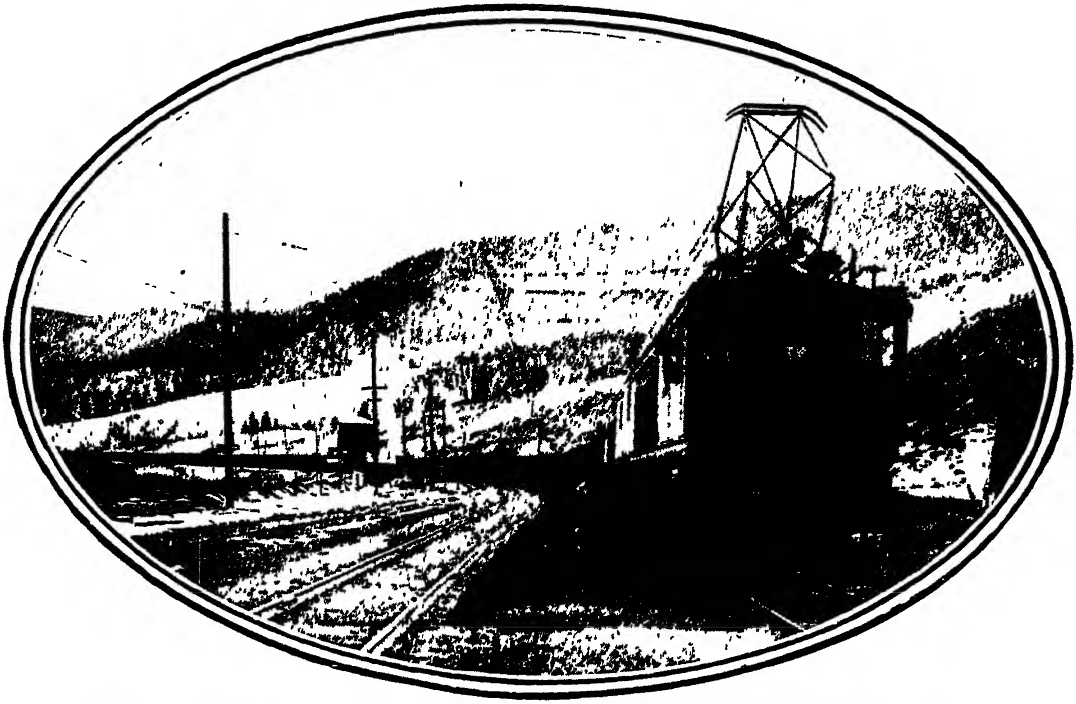
To meet the most severe conditions encountered in mining and sinking operations a special type of submersible has been evolved. This is of the multi-stage type. The stages at present introduced run up to six. That is to say, six pumps are coupled in series side by side, or rather one under the other for convenience and compactness, the motor being placed vertically above, and the whole equipment carried in a simple substantial cage. A six-stage 4-inch pump of this type, delivering 300 gallons a minute to a height of 500 feet, and driven by an 85-brake-horse-power motor by three-phase current, 50 cycles 220 volts at 1,420 revolutions per minute, has an over-all height of 87 inches, a width of 37 inches, and is 32 inches in depth.

The submersible electric motor has also demonstrated its suitability for installation in the coal-mine for the performance of power duties, more particularly in those workings where inflammable gases prevail. Therewith no apprehensions concerning explosion from sparking of the motor need be entertained. This is impossible, because the whole of the windings and working parts are continuously surrounded by water, no matter whether the motor be working submerged or otherwise.



WORKING AMIDST THE WASTE OF WATER

The submersible electric motor-pump can be rigged up anywhere. In the above instance it was placed upon the deck of the submerged wreck, and hurled the water drawn from the flooded ship into the open sea.



By courtesy of the International General Electric Company.

ECONOMICAL AND EXPEDITIOUS FREIGHT HAULAGE THROUGH THE ROCKY MOUNTAINS

Goods train, weighing 1,450 tons, hauled by a single electric locomotive at Donald, the summit-level of the railway, 6,352 feet above sea-level.

The Electrification of a Trans-continental Railway—II

HOW THE HEAVIEST GRADIENTS IN THE ROCKY MOUNTAINS ARE OVERCOME

THE introduction of electric haulage compelled a complete revision of the system of operating the trains over the 440 miles of the Rocky Mountain zone. Under steam conditions all eastbound passenger trains out of Deer Lodge had to be double-headed over the Continental Divide to Three Forks. The result was that, to ensure the return of the "helper" locomotives to their designed stations, many westbound trains had to be handled by two engines when double-heading was really unnecessary. Again, all steam trains from Butte to Donald had to be provided with a "helper"; likewise trains running in the opposite direction between Piedmont and Donald. With the "helper" the steam-hauled trains could notch about 21 miles an hour up the bank of 1 in 60 between Newcomb and Donald, provided there were not more than eight vehicles representing 650 tons attached; while on the 20-miles pull against the collar at 1 in 50 from Piedmont to Donald, the speed was about 18 miles per hour. Under electric operation faster speeds—28 and 25

miles per hour respectively—are attained with heavier train weights on these two uphill stretches.

Under steam conditions the 220 miles between Deer Lodge and Harlowton were covered in about 8 hours running-time. Although the electrics are speedier and can cover the distance in 6½ hours, the service was not accelerated. The speeds in the various sections were adjusted to get more uniform running through the division while, at the same time, the electrics having 1½ hours in hand can make up any time which may have been lost on the preceding steam section. Formerly there was one brief section which retarded the steam locomotives. Owing to the heavy grade a "helper" had to be taken on to lift the train up the hill. The electric does not require this assistance, because it is able to put forth the little extra effort required to meet the situation without suffering any injury from the overload, which is only of 6 to 7 minutes' duration. Delay in picking up and dropping a helper is thus eliminated.

Electric Traction in Passenger Service

The local passenger train running between Harlowton and Deer Lodge is generally composed of three coaches weighing 210 tons. There are 19 station stops, as well as several halts, throughout the journey. Electric traction in this service has proved distinctly advantageous, owing to the greater starting effort and more rapid acceleration. For this duty one-half, or a single unit, of the standard electric locomotive is employed, the design of the locomotive—two identical units coupled together—facilitating such a novel division.

It is in the handling of the freight service that the virtues of electric traction have been most graphically demonstrated. These trains are composed of cars from many different systems, and are of varying capacities. Each car has its individual air-brake equipment adapted to the peculiar conditions of the system to which it belongs, though, of course, it is the Westinghouse brake which is in universal application. Nevertheless, the situation is vastly different from that arising when all the vehicles belong to one company, because then there is uniformity of the brake equipment, which is probably of greater significance in the handling of these trains, owing to their length and weight, than passenger trains.

Goods Traffic under Electricity

The handling of the freighters under electric operation is quite an art. When there are 80 cars, representing possibly 3,000 to 3,500 tons, behind the locomotive the need for skill in manipulation becomes readily apparent. In the first place the braking facilities must be in perfect order and, accordingly, the air-brake connexion has to be carefully tested the moment the locomotive is coupled up to make sure that all the brakes are working satisfactorily and smoothly. After the brakes have been once applied and released while the train is standing still, the equipment on each vehicle is inspected by the crew of the train to make doubly sure that everything is in perfect working order.

The train is now ready to start, and it must be got under way without shock. The coupling of each vehicle can be distended by about 12 inches before the pull is conveyed to the vehicle to which it belongs. Allowing one foot per car it will be seen, in the case of an 80-car train, that the locomotive has to travel 80 feet before its haulage effort is conveyed to the rear brake-van or caboose. It is thus readily possible to set up a series of jerks in starting a train. Should the engine set off suddenly the jolt may easily prove disastrous to the coupling.

To secure smooth starting, the locomotive should move very gradually at first until all the possible slack is taken up. This is assured by providing the

controller with a large number of steps, an outstanding feature of the electric locomotives used upon this railway. The driver moves the handle of his controller on and off the first notch two or three times, thus getting the locomotive to take up the slack in the forward part of the train. At the first notch the locomotive develops about 17,500 lb. of tractive effort, and each succeeding notch represents approximately a similar increment.

The driver advances the locomotive on to the second and successive notches gradually to increase the speed of the locomotive until it has moved forward about the same distance as is represented by the aggregate of slack in the train —80 feet in the case of an 80-car train. If the starting is performed neatly the whole train will be got under way without the slightest jerk, but even when finally started, an appreciably long time is occupied in accelerating to the series position of the controller.

Starting a Train in Winter

Although starting is such a delicate task under favourable conditions, it is infinitely more complex and sensitive in winter when the temperature is low. As a rule the rails are covered with rime or snow, conducing to ready slipping of the driving-wheels when the current is switched on, with the result that liberal sanding is necessary. The situation is aggravated by the circumstance that the oil in the journal-boxes of the cars congeals, and it becomes necessary to reduce the lubricant to its normal fluid condition before attempting speed.

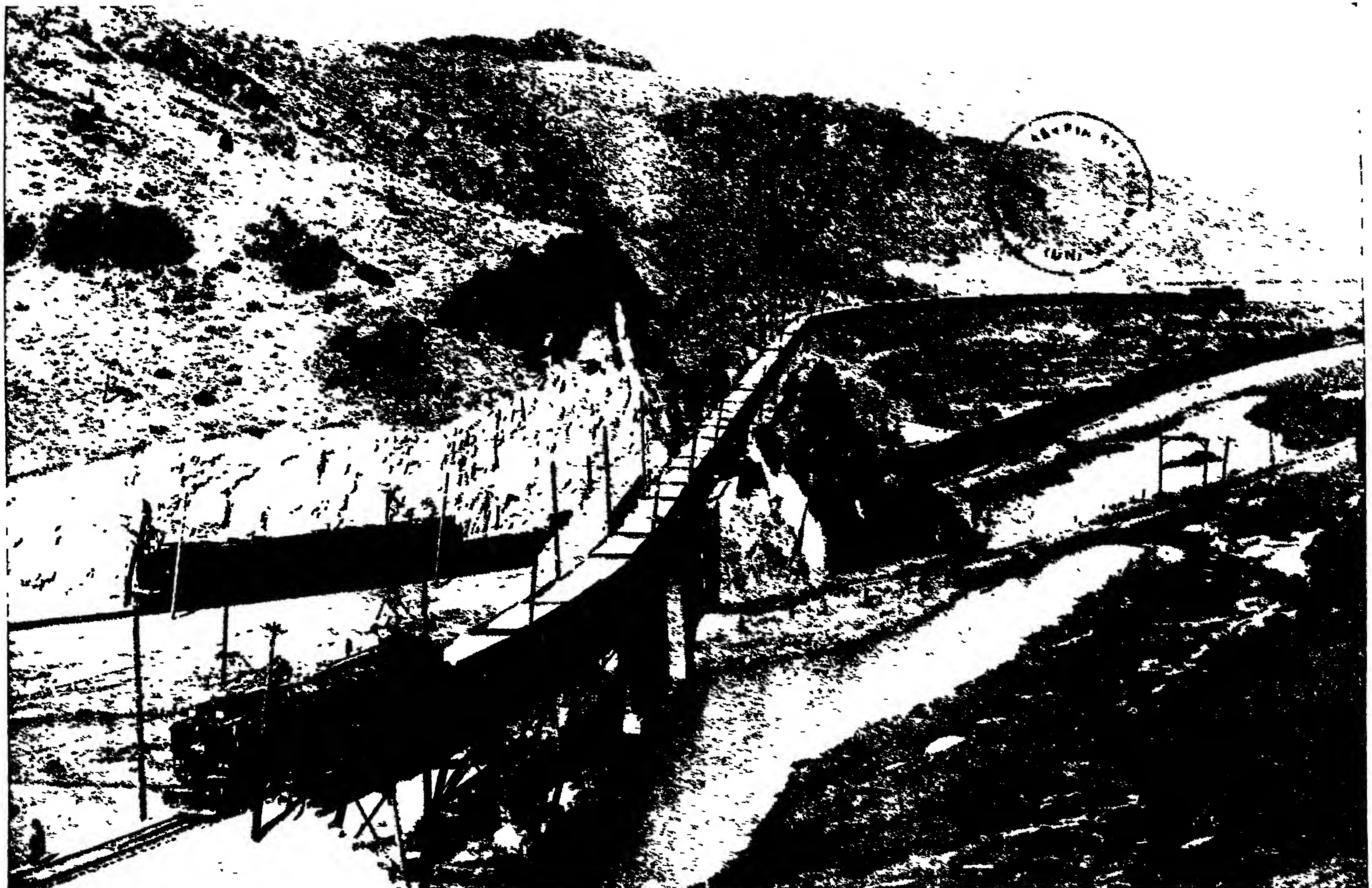
When the weather is very cold, reduction of the weight of the load is inevitable, owing to the train friction being so exceedingly high; the reduction often amounts to as much as 30 per cent. of that normally handled. Even when the train has been set in motion it is necessary to run it for two or three miles at a slow speed, keeping the controller in series position to allow the journals of the cars to warm up sufficiently to thaw the lubricant, and thus reduce the friction. If, after running a few miles, the train is forced to come to a standstill, and suffers delay for a few minutes, the journals cool down, and the oil congeals once more, rendering it necessary to repeat the trying starting operation.

As the running becomes easier the locomotive is gradually accelerated until the full parallel position of the controller is attained. This condition is maintained until the current falls to about 150 amperes per motor, when the controller is advanced to the last notch, thereby shunting the motor-field about 50 per cent. and increasing the train speed by about 5 miles per hour. In carrying out this final movement the driver takes advantage of any stretch of level track which may present itself, especially if he has a dead weight of 2,500 to 3,000 tons behind him.

"Helper" Service Reduced

" Helper " service in the movement of the freight trains has been greatly reduced. Westbound, the train, representing a dead weight of 2,500 tons or so, leaves Harlowton drawn by one electric as far as Bruno. This is at the bottom of the last heavy pull to Loweth, the summit-level of the Belt Mountains. The bank rises at 1 in 50 for 5 miles, and to overcome this stretch the train is divided and run to the summit in two sections, where it is recoupled to form a single unit. Division in this manner is easier and more economical than the utilization of a "helper" upon the five-mile bank because, after riding the crown of the hill, the train has a 50-miles' coast all the way to Lombard, followed by an easy climb to Piedmont, 105 miles beyond Loweth.

Now comes the 20-miles' pull uphill continuously at 1 in 50 to gain Donald, the station at the summit-level of the Continental Divide. To overcome this section a " helper " is necessary. It is taken on



By courtesy of the International General Electric Company.

WHERE STEAM HAS GIVEN WAY TO ELECTRICITY IN RAILWAY OPERATION.

An ore train of 60 laden cars of the Butte, Anaconda and Pacific Railway, hauled by two 2,400-volt, direct-current, 80-ton locomotives, crossing a bridge. Below, a freight train of the Chicago, Milwaukee and St. Paul Railway, drawn by a single 3,000-volt, direct-current, 283-ton locomotive.

at Piedmont to accompany the train over the hump and down into Butte about 15 miles west of the summit, and near the foot of the 1 in 60 grade on the western side of the mountains. But this descent is easily accomplished by the aid of a single locomotive; the "helper" unit is shut down during this downhill run. Although the descent is steep a single locomotive can easily hold a train weighing 2,800 tons in check, so highly effective is the regenerative brake system. Clearing Butte, where the "helper" is discarded, there is an excellent downhill run to Deer Lodge, the divisional point, and the freight trains generally make from 25 to 30 miles per hour through this 40 odd miles; easing up where necessary to round the curves, the slowing down is for the most part accomplished by regeneration. It may be mentioned that the speed attained during this last lap constitutes the running-speed limit for these freight locomotives, and it may also be pointed out that one-half of the locomotive—one unit—can generally furnish the slight braking effort demanded to hold the train in check.

For the eastward run the freight trains are generally made up at the Butte yards, the average weight being 3,000 tons. Being faced with a climb of 1 in 60 almost immediately after leaving the station, to gain Donald, a "helper" locomotive is taken on, and this second unit runs through to Piedmont; the descent from the summit to the station in question is at a speed ranging from 18 to 25 miles an hour according to the weight of the train. However, on the downward run, owing to the severity of the curvature, the speed often has to be reduced to less than 18 miles; this easing up is achieved by the control of the regenerative braking system.

Average Load of 3,000 Tons

At Piedmont the "helper" locomotive is dropped, and the train continues its journey with a single locomotive through Three Forks to Lombard; this downhill run is made with one-half of the locomotive entirely shut down, especially as, often at Three Forks, the train weight becomes reduced to 2,500 tons owing to several cars being shed at this point. But Lombard lies at the bottom of the long steady 50-miles upward pull to Loweth, where the grade sometimes reaches 1 in 100, and so a "helper" locomotive is taken on at this point to assist the train over the Belt Mountains. Fortunately, during this run, the grade frequently eases sufficiently to enable the locomotives to make use of the field shunting position of the controller, put up a good speed, and thus make excellent time. The summit negotiated there comes the coast all the way to Harlowton, some 45 miles, and on this section the train can notch the highest speeds permissible for the freight hauliers.

From what has been related it will be seen that on the 220 miles between Harlowton and Deer Lodge constituting one electrical division, the assistance of a "helper" is only demanded over one section in both directions, namely between Butte and Piedmont, and this is where electric operation has proved so eminently advantageous. For instance, at Three Forks, where the crew—not the locomotive as under former steam practice—is changed, all trains are delayed for 10 to 30 minutes, sometimes longer. This is due to the movement of other trains and the time-schedule which has been drawn up. Under steam operation the delay was from two to three hours because, at this point, it was necessary to make a thorough inspection of the locomotives and the brake equipment throughout the train. The coast from Donald, and the exclusive use of the brakes for dissipating the entire energy of the descending train, invariably involved the replacement of worn brake-shoes and the execution of other minor repairs. But under electric operation this duty

Delays Reduced to the Minimum

has been eliminated because in the descent the air-brakes are scarcely touched; the train is held completely in hand by the regenerative braking of the locomotives. The former large force of experienced men retained at Three Forks, together with sufficient equipment to conduct the necessary brake repairs, has been replaced by one electrician, and his sole task is to examine the shoes of the pantograph collector and to change them if necessary, as well as to furnish whatever insignificant supplies the motor-driving crew may desire.

The "Helper" Centred

Although the employment of a second locomotive—"helping service"—has been virtually abandoned, or at least reduced to the minimum, it is interesting to observe the novel departure in working which has attended the introduction of the electric. When the new era was inaugurated the officials concluded that the most satisfactory position for the second locomotive would be at the front end of the train, thus embracing the practice of "double-heading." The idea was that dual pilot effort would be necessary to hold the train in check during the descent of the steep banks, the locomotives operating in multiple unit, but when it was found that a single locomotive could hold the train this idea was abandoned. Then it was conceived that steam-locomotive practice, in which the second driving unit is attached to the rear of the train and thus is called upon to assist by exerting a pushing effort, would be the most satisfactory and efficient method of grappling with the issue. But this time-honoured system was abandoned in turn. It was ascertained, as the result of experiment, that the most efficient position for the "helper" locomotive was about the centre of the train; the latter was thus divided into two sections, but fully coupled up and run as a single unit, each locomotive being called upon to handle a trailing tonnage within its own hauling capacity.

Placing the "helper" locomotive in the centre of the train has compelled a revision of the methods of starting the train—one in which there is an increased demand for skill of a peculiar order. The "helper" locomotive is coupled to the section in front of it. When all is ready the air-brakes are applied throughout the train and released as in single electric haulage; the train is now held stationary by the independent brakes on the two locomotives.

Method of Starting the Train with the "Helper"

The motorman on the locomotive at the head of the train gives two long whistles to indicate to the motorman on the "helper" that he, the leader, is "Off!" If everything is satisfactory and the "helper" locomotive is ready, the second motorman replies with his whistle. The motorman on the leading locomotive now starts in the usual way. He moves his controller to the first or second notch and releases his independent brakes. The power applied is sufficient to prevent the locomotive starting back and bumping the train. Directly he has released his brakes the motorman advances his controller slowly until the train begins to move, or he has approached as near as he dare to the point when the driving-wheels will slip and revolve uselessly. This initial movement is to take up all the slack in the train as represented by the limit of movement of each coupling.

After he has answered the leading locomotive's "Off!" whistle the driver of the "helper" locomotive, hands on controller and brake respectively, keeps his eye fixed upon the car immediately in front of him, to which he, of course, is coupled. The moment he sees its draw-bar commencing to stretch, indicating that the slack of the train has been taken up to this point, he advances his controller to the first or second notch and releases his

locomotive's independent brakes. He then advances his controller slowly until either his part of the train joins in the general starting movement or his wheels commence to slip. When the train starts the motormen on the two locomotives watch their respective ammeters closely, continuing to accelerate gradually as near to the wheel-slipping point as it is practicable to do until they gain the full parallel position.

It will be realized that the motorman of the "helper" locomotive, after acknowledging the starting whistle, is guided wholly by the movement of the draw-bar of the vehicle immediately ahead of him. But he may not be sufficiently alert or dexterous in picking up the general starting movement at the critical moment, or he may be somewhat uncertain of what the leading locomotive is doing. Accordingly, if the motorman of the leading locomotive does not secure movement of the whole train within the time he considers adequate, he slowly retards his controller lever and thus causes the train to back gradually against the "helper." This almost imperceptible "bump" is the signal to the motorman of the latter to be ready to start. The instant the motorman of the leading locomotive feels the train pressing against him, as the result of the full compression of the draw-bars throughout his section of the train, he sets out to start again in the manner described.

CROSSING THE AMERICAN CONTINENT ELECTRICALLY.
The "Olympian" and "Columbian," the two transcontinental "Limiteds" of the Chicago, Milwaukee and St. Paul Railway, hauled by Westinghouse electrics, at Butte station.

It may be necessary to repeat this backing operation several times, but in this event each succeeding "rolling back," as it is called, is made with increased severity to remove any doubts which may be lingering in the second driver's mind

concerning the intentions of his comrade in the leading locomotive. If the train be brought to a standstill on a heavy grade the difficulties of starting become very materially accentuated. Often the driving-wheels of the locomotives will slip, to spin idly, necessitating liberal sanding and the recommencement of the whole cycle of operations.

If starting be a delicate and extremely dexterous operation, it is certainly equalled by that of stopping the train, inasmuch as the retarding movement must be applied simultaneously by the motormen of the two locomotives. The man responsible for the control of the "helper" is wholly guided by the behaviour of the car immediately in front of him. To bring the mass to a standstill the leading motorman warns his comrade by whistle, and then notches his controller very gradually, carefully slowing down meanwhile. The motorman on the "helper," after receiving the warning whistle, keeps his eyes fixed upon his ammeters, the needles of which commence to ascend their scales. Immediately the second motorman shuts off his controller gradually, taking care to keep the current at a slightly lower value than is required when running. He continues this action until the train comes to rest, when he applies his independent brakes and shuts the controller right off. The motorman on the front locomotive now does likewise, and, if the circumstances so demand, will apply the train brakes to assist in the process.

Stopping a Train an Equally Delicate Operation

When the train is descending a sharp grade and a stop is necessary the foregoing cycle of operations is somewhat modified. The train is probably running under regeneration conditions. The motorman on the leading locomotive gradually applies the air-brake to the train, and, as the speed falls, he notches back his controller; the independent brakes are kept off. In due course regeneration ceases when the main controller is shut right off to prevent the train coasting, and the train brakes further applied to bring the train to a standstill; the independent brakes of the locomotive are meanwhile brought into service to assist in this connexion. The latter are not applied until regeneration has ceased. A similar practice is followed by the motorman of the "helper" locomotive. When the train has been brought to a standstill the air-brakes are released and the whole string of vehicles is held stationary, solely by the independent brakes of the leading locomotive.

Restarting upon a steep falling grade demands more care than starting under usual conditions. The motorman on the leading locomotive releases his independent brakes. As a rule the engine will immediately commence to move under gravity, but power may be required to impart the necessary starting impulse. In any event the greatest care is demanded inasmuch as, if the locomotive be permitted to start too quickly, sufficient shock is likely to be recorded in the centre of the train to break the coupling. Starting effectively accomplished, the train is permitted to gather a speed of about 19 miles an hour, when the leading motorman makes a slight application of the train brake, notches out his controller to the full parallel position, and commences regeneration by means of the controller governing this braking action. Directly regeneration commences the train brakes are released.

Restarting on a Steep Falling Grade

There is one feature of moving a long and heavy freight train in this manner over the mountains which is invested with interest. The crown of the hill is negligible; there is no perceptible length of level track. Consequently the leading locomotive having overcome the hump is descending the opposite bank while the "helper" is still climbing the approach

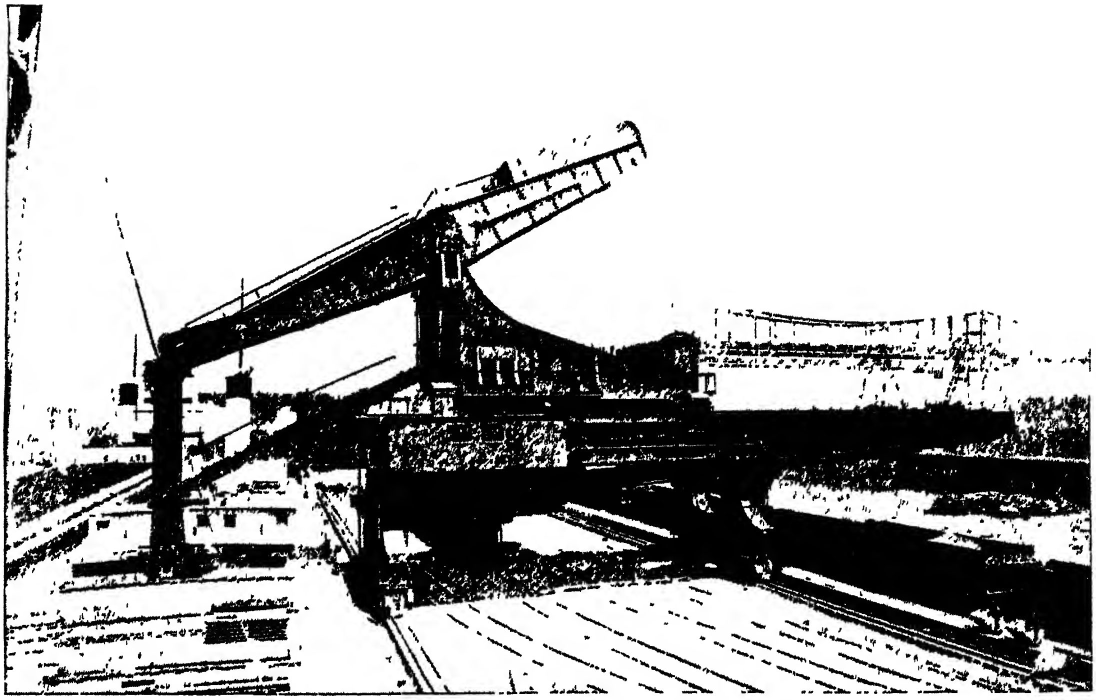
to the summit. As the leading locomotive commences to run downhill the motorman gradually brings on the controller governing the regenerative action; the main controller meanwhile is left in the full parallel position. The locomotive commences to regenerate, and under the braking action thus produced the cars, as they come over the hill, encounter resistance and commence to press upon the locomotive. This "bunching," as it is termed, continues to pass right through the train until at last it reaches the car immediately in front of the "helper" locomotive. This vehicle being checked commences to press back against the second locomotive which is still driving. The instant the "helper" locomotive motorman observes the draw-bar of the car immediately ahead of him commence to crowd back against his engine, he too swings in his braking controller. He does not proceed so far as the leading motorman, because the second locomotive motorman has nothing to do with the control of the train; this is the sole responsibility of the man in the front driving unit.

As the result of the high driving proficiency attained, and with the accumulation of experience and practice, the length and weight of the freight trains is being persistently increased. Whereas the steam Mallets on the maximum grades could cope only with 1,700 tons, the new electrics are handling trailing loads ranging from 2,500 to 3,000 tons, and at practically twice the speed recorded under the steam conditions. From the passenger point of view the results are equally satisfactory.

Those who are responsible for the destinies of the Chicago, Milwaukee and St. Paul Railway are to be commended upon their enterprise and audacity in shouldering the capital expenditure of £2,400,000—$12,000,000—which the scheme involved; but what this triumph of electricity really signifies is most convincingly expressed by the administration of the railway—"The Milwaukee road has forgotten that the Continental Divide exists."

A SOURCE OF CHEAP ELECTRICITY.

Rainbow Falls of the Missouri River, tamed by the engineer. The 35,000 kilowatts derived from this fall form a contribution to the hydro-electric supply of the Montana Power Company, whose enterprise assisted electrification of the transcontinental railway to a very material degree.



15-TON HULETT ELECTRICALLY OPERATED UNLOADER AT WORK

This illustration gives a general idea of the massive proportions of this machine, which requires only three men to work it. The bucket-leg is emerging from the hold of the ore-carrier alongside. Beneath are railway tracks for direct discharge into wagons if desired, and storage bin at right to which the cargo can be transferred.

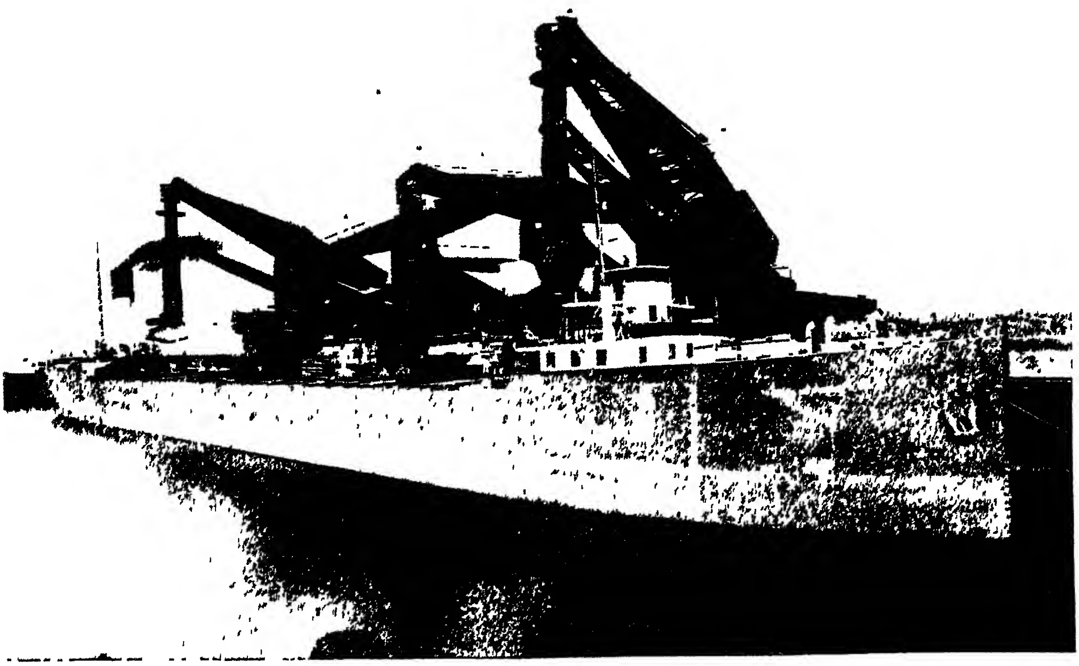
Unloading Ore Automatically upon the Great Lakes

AN ELECTRICALLY OPERATED MULTIPLE MACHINE WHICH DISCHARGES AND DISTRIBUTES BULK CARGO

THE development of the iron ore carrying trade over those inland seas — Lakes Superior, Huron, and Erie — of the American continent, constitutes one of the most fascinating mercantile romances of to-day. Huge fleets of vessels, specially designed for the traffic, have been built. They are distinctive craft of great length, with the navigating bridge and quarters planted in the bow, and the engine-room set at the extreme stern. This leaves a huge rectangular well, or single hold, extending unbrokenly from end to end of the ship, which thus resembles a huge box; it is utterly devoid of any superstructure, and the hold is covered by two long rows of hatches. These vessels run up to 600 feet in length, and are capable of carrying 10,000 to 12,000 or more tons of ore in a single shipment.

In setting out to exploit the practically inexhaustible ore beds of Minnesota in this manner, the industry was confronted with one grave disadvantage. Navigation

of the lakes is possible for only about seven months during the year. For the remaining five months marine traffic has to be abandoned, because the huge inland seas are icebound, and to such a degree as to resist the passage of the most powerful vessels yet skilled in the unloading of ships. The former paid but little regard to his colleague in the other sphere, because his problem was to design vessels capable of moving the greatest volume of ore within the shortest possible time. On the other hand



FOUR UNLOADERS SIMULTANEOUSLY DISCHARGING ORE FROM S.S *ZENITH CITY*.

Passing from right to left the bucket-leg of the first unloader is shown descending into the hold with the bucket fully distended; the second is passing through the hatchway; the third is grabbing its load; while the fourth is withdrawing from the hold with fully charged bucket to empty into the hopper upon the machine.

built. Consequently during the open season ore-shipping is conducted under the most intensified conditions, inasmuch as sufficient raw material has to be brought south during this period to carry the steelworks through the five months of winter.

Such enormous movement of ore by water would be of no avail without adequate unloading facilities at the port of discharge. The ships are filled at the northern lake points from huge bins through chutes, a simple process, because gravity is the only force required. No such favourable factor can be applied to the unloading of the craft. Accordingly a spirited struggle arose between the shipbuilder and the engineer the mechanical engineer was confronted with the task of devising machinery of such a nature as would reduce the stay of the incoming vessel to the absolute minimum. At the moment honours are easy. If anything the advantage is in favour of the mechanical engineer because, by the aid of the marvellous machines which he has contrived, he has reduced the stay of a 10,000-tonner to such a brief period as scarcely to allow the ship's officers the opportunity of walking ashore to stretch their legs.

One of the most remarkable of these machines is the Hulett unloader. It is wholly automatic in its action, and ex-

perience has proved it to be one of the most successful devices yet built for the fulfilment of the peculiar and exacting duty in question. Its proportions are immense, but its mechanism is free from complication. From the capital point of view it must be accepted as an expensive unit of equipment, but its wonderful earning power cannot be denied. Although it unloads, weighs the ore, and discharges it either directly into waiting railway trucks, or into the capacious storage bins, it is not a combined machine. It is an unloader pure and simple, and as it is automatic throughout in its operation, the ore is not touched by hand at any stage during the discharging cycle. Furthermore its controls, owing to the recognition of the possibilities of electricity, have been brought to a high standard of perfection and one of extreme delicacy. So far as the human factor is concerned, it represents one of the most remarkable labour-savers yet contrived in this field.

Outline of the Unloader

The machine comprises a massive main framework mounted on trucks. The front runs over a track laid along the edge of the dock wall, while the rear truck is carried upon a second and similar track laid parallel with, but approximately 65 feet behind, the former line. In other words, it may be said that the machine moves over a railway track of about 65-feet gauge. The space between the two trucks forms a shallow well in which a number of standard gauge railway tracks are laid side by side for the reception of the railway cars into which the ore, withdrawn from the steamers, may be directly transferred if desired. The main frame of the unloader, mounted upon the trucks, is extended rearwards by means of a cantilever for about 57 feet, thus spanning the storage bin or dump pile where the ore may be discharged if preferred. This main frame is driven up and down its wharf track by a 100-horse-power electric motor. Thus it can be brought to any position convenient for the unloading of the vessel moored alongside. The berthing of the steamer is therefore simplified.

The total length of this main frame, which is of massive construction, with its cantilever, is about 135 feet, and its girders constitute a support for runway rails along which a trolley travels. This trolley has a front six-wheeled truck running upon the upper face of the rails, and a rear truck, the wheels of which engage with the underface of the runway. This trolley is driven by a 120-horse-power motor. Its length of travel is 78 feet along the main frame, which extends from the front end of the latter, overhanging the dock wall, to the opposite end of the cantilever.

Usefulness of the Bucket-leg

The trolley supports a balanced walking-beam; at its outer end depends a leg having at its lower extremity a capacious bucket. The horizontal movements of the bucket are accomplished by moving the trolley backwards and forwards upon its track laid upon the main framework, while the vertical movements are carried out by the operation of the walking-beam. By this arrangement it is possible to swing the rear end of the beam through an arc having a radius of about 44 feet 6 inches.

The elevation of the bucket-leg, or movement of the walking-beam hoist, is carried out by a 275-horse-power electric motor, and, when fully elevated, the rear end of the walking-beam is resting between the girders forming the tail of the trolley. As the walking-beam is not balanced, the front being heavier than the rear end, power is not required to lower the bucket-leg. Directly the brakes of the hoisting mechanism are released, the bucket-leg descends by gravity. When the walking-beam is brought to the horizontal position its outer end, to which the bucket-leg is pivoted, is about 60 feet above the level of the dock. Upon the rear end of the

BUILDING THE WINTER IRON ORE PILE WITH THE ELECTRIC STOCKING BRIDGE.

As the great lakes are closed to navigation for five months of the year, huge reserves of ore have to be created to keep the steel-works supplied during the winter. The stocking or ore-rehandling bridge is the adjunct to the unloader This illustration shows a rehandling bridge, with a span of 238 feet, 90-feet tower cantilever on the right, and shear leg 50-feet cantilever on the left, transferring ore from the unloader dump to the main storage. The tower and shear leg travel along tracks upon the tops of the walls. The underside of the bridge has a track for the travelling electric trolley and the 10-ton bucket. On the right four Hulett unloaders are seen discharging into the unloader storage bin.

walking-beam is a cabin which houses the hoisting mechanism; ropes from its winding-drums pass round sheaves placed in the rear end of the trolley, and anchored to the rear end of the walking-beam.

The foregoing may be regarded as the fundamental unloading elements of the machine, but there are one or two other units of equal interest and importance. Placed between the principal girders, near the forward end of the main framework, is a receiving hopper, which is introduced to receive the ore brought in by the unloading bucket. This hopper is of sufficient capacity to receive some three full bucket loads; its function is to act as a balancing point for the ore between the bucket and the railway cars or storage, as the case may be.

Larry in Co-operation with the Main Hopper

The bottom of this hopper is fitted with gates which, when opened, allow the contents to fall, as required, into another hopper borne by a larry running on an auxiliary track suspended from the under side of the main girders. When the larry has received its load from the main hopper it moves to a point to allow discharge direct into the waiting railway vehicle beneath. Thence the load may be immediately carried to the steel-works, or into the temporary storage bin placed under the cantilever at the rear of the machine.

It will be realized that several rows of cars may be disposed upon the railway tracks beneath the main span of the girders, some of which may be charged, while others are empty. By giving the larry movement to and fro through this span, it is not necessary to shunt the empty vehicle to a central point to receive its load. It can be filled upon any track; it is only necessary for the car to be under the main frame. There is one point which demands explanation. If the ore is transferred from the ship to the storage pile at the rear, it cannot be subsequently moved from the latter to the railway cars by means of this machine. The appliance in question is simply an unloader working from ship to shore. Loading from the storage pile to railway cars demands the employment of other mechanism.

A Mouthful of 20 Tons

One of the most striking features of this wonderful machine is the bucket carried at the lower extremity of the leg attached to the walking-beam. This bucket is of the shell type, and each section is fashioned out of a single piece of plate formed to the shape required. As a rule the shells are fitted with manganese steel cutting-lips to resist the abrasive action of the ore. The bucket shells themselves are carried on heavy cast-steel arms, mounted on rollers, travelling in guides in the fixed portion of the lower end of the bucket-leg. In the larger type of machine the bucket is able to take a mouthful of 20 tons of ore, whereas that used with the smaller type of machine is about 10 tons.

In the case of the first-named, when the jaws, or shells, are fully distended, the distance from lip to lip is 24 feet 3 inches, so that this bucket could readily grab the average suburban dwelling into its mouth. Moreover, the shell arrangement enables the bucket to work upon the lowest level of the ore; in closing, the jaws exercise a scraping effect upon the floor of the hold. The bucket can also be swung round in any direction so that it is unnecessary to shovel the ore to enable it to receive a full charge, except during the closing stage of the unloading operation, when the remaining thin layer is scooped into a heap for the convenience of this insatiable maw.

The operation of the bucket is controlled from a small cabin placed in the leg, and immediately above the bucket itself, wherein the operator has a close and uninterrupted view of his work. For closing the bucket a 120-horse-power motor is employed. This may seem an excessively powerful unit for such work, but it must

be remembered that in making its bite a powerful digging effort has to be put forth, notwithstanding the fact that the ore may be of the consistency of sand. The motor for carrying out this duty is mounted in the machinery house upon the rear end of the walking-beam, and the ropes actuating the closing mechanism are carried from the control cabin through the walking-beam and down the bucket-leg to a powerful drum placed in the lower end of the last-named, immediately above the operator's cabin at the bottom of the bucket-leg. This power-drum is geared on either side through massive chains to the bucket mechanism itself, the winding of the chain in one direction drawing the opposing shells together. The bucket is compelled to release its mouthful by reversing the motor; the shells are thus forced open by means of another chain carried in the centre of the bucket-leg between the two closing chains.

A 25-horse-power Motor Rotates the Bucket

The bucket is given the motion of rotation about its vertical axis, and this is effected by means of ropes attached to a segment on the bucket-leg itself. These ropes are carried back in the walking-beam to a rotating mechanism placed adjacent to the bucket-closing mechanism. The bucket-leg itself is carried on a roller-bearing attached to the top end of the leg. The rotating motion is introduced to allow of the bucket being turned at right angles to the hatchway, after it has entered the hold; thus as great a reach as possible lengthwise of the boat is obtained. In this way the bucket is able to gather ore which is not directly beneath the hatch opening. For rotating the bucket in the manner described a 25-horse-power motor is employed.

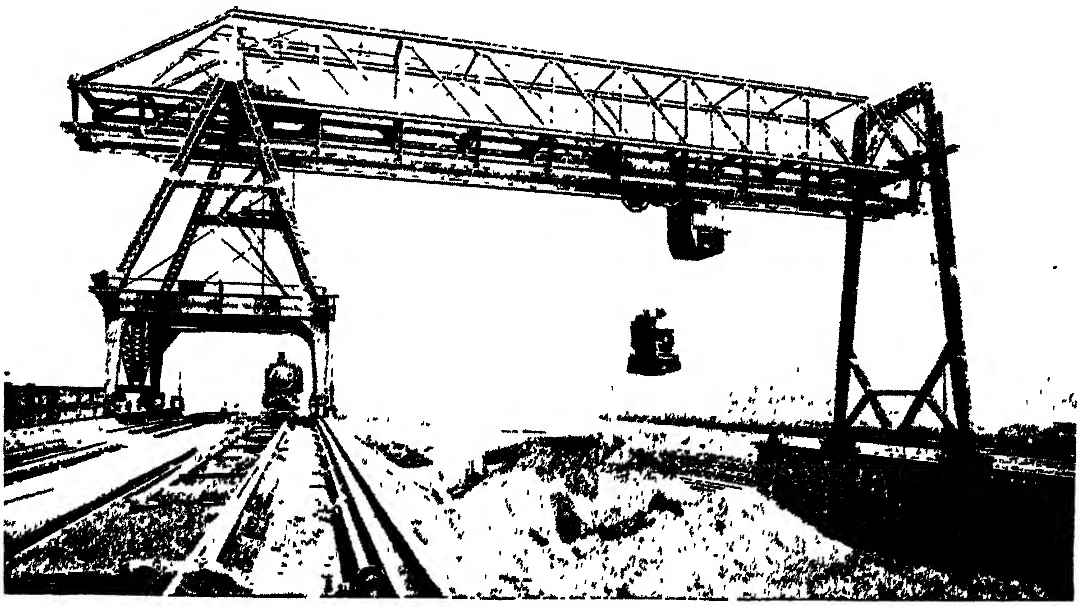
The larry hopper of the larger-sized machine, to which reference has been made, has been given the designed capacity to fill a railway vehicle in two discharges. The device is fitted with a bottom arranged in the form of gates, suspended from the sides of the larry frame, and operated through connecting rods and cranks, also connected to the main larry frame. The power required is furnished by a 40-horse-power motor carried at the rear of the larry. The gates are so disposed that either all, or only a portion of, the contents may be discharged. The hopper of the larry is hung in the larry frame on scales to facilitate the weighing of the ore, and a record of the operation is automatically secured.

Winding-drums Actuated by a 150-horse-power Motor

The larry is moved backwards and forwards through its limit of travel by mechanism mounted on the larry itself. This comprises winding-drums, actuated by a 150-horse-power motor, upon which ropes are wound; the ends of the ropes are attached to the rear end of the cantilever on the main framework. The larry track, inclined at a grade of 6·7 per cent., extends from the front to the rear end of the cantilever. The larry is pulled up this incline by means of these ropes, but on the return descends by gravity.

It will be observed that electricity is employed throughout for the operation of this machine, although in a few installations steam is employed; but the former gives the most efficient and economical working. The usual design calls for 220 volts direct current; alternating current is never employed. The various distinct operations of the machine are carried out by an installation of eight motors aggregating 930 horse-power. The power of the individual motors ranges from a maximum of 275 horse-power for the walking-beam hoist to the minimum of 25 horse-power for rotating the bucket. The motor control equipment is of the magnetic switch type throughout, with master controllers in the cabs of the operators, which are placed in the bucket-leg

and on the larry respectively. Current is supplied by means of insulated conductor rails extending the length of the main runways, and collected therefrom by means of pick-up shoes attached to the trolley, for distribution to the various movements of the trolley along the main frame track, as well as the movement of the machine itself along the dock from hatch to hatch. Consequently he is able to bring the machine to the position desired for favourable working. Control from such



FROM STORAGE PILE TO RAILWAY WAGON

Stocking bridge with a centre span of 145 feet. The tower cantilever spans two railway tracks, permitting the trucks to be brought beneath to be filled. Side view of the bucket closed and half hoisted for movement to the railway tracks along which the train is approaching.

points of the machine. A similar collecting device is also employed for the supply of main current to the trolley.

In view of the work accomplished, the circumstance that such a ponderous quick-acting machine can be completely controlled by three men, is certainly remarkable, and testifies to the perfection and simplicity of the mechanism which has been evolved. The bucket-leg operator is stationed in the cabin provided for the purpose, and has a complete view of the operations.

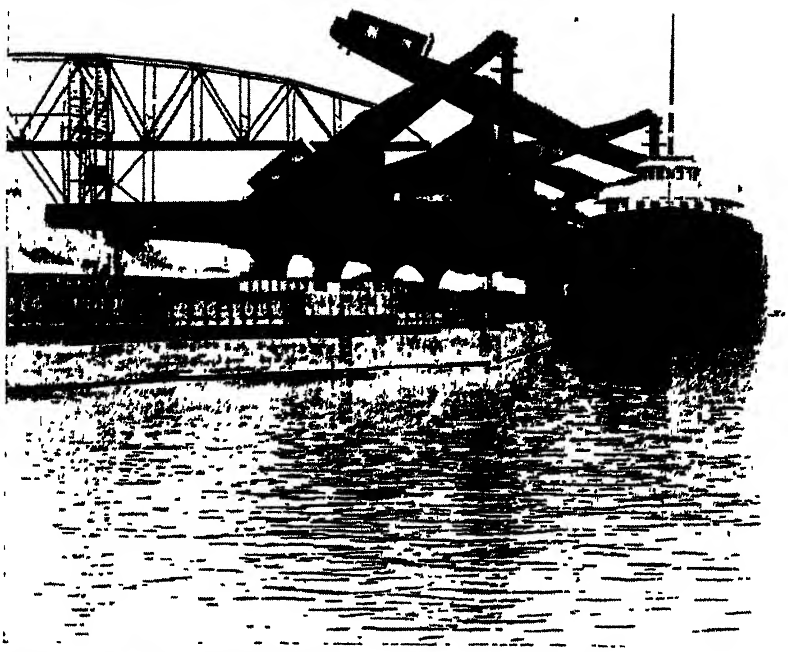
This man travels up and down in the leg the whole time unloading is in progress. He has complete control not only of the elevation and lowering of the bucket-leg but also of the backward and forward

a station may seem strange, when one recalls that such positions are, as a rule, somewhat elevated. The larry operator is stationed in a cab on the larry, and he is responsible for the movement of the larry, the actuation of the larry gates, the weighing and disposal of the ore.

The operation of the machine is as simple as its design. Ere the laden ore steamer has been made fast to the dock, the operator in the bucket-leg cabin has set the 100-horse-power travelling motor in action to bring the machine opposite the hatch desired. The brakes controlling the walking-beam hoist motor are released, and by gravity, the bucket with jaws distended in anticipation, is lowered through the

hatch, the bucket operator manipulating the 25-horse-power motor governing the axial rotation of the bucket to steer it through the hatchway.

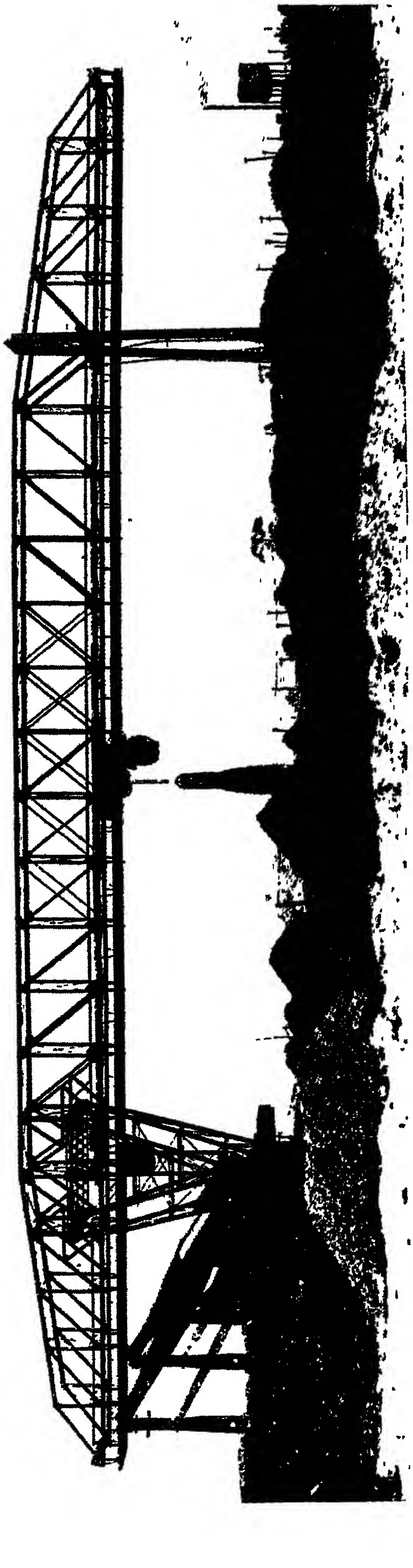
The fully distended jaws of the bucket rest on the bank of ore in the hold. The 120-horse-power bucket-closing motor is set going, and the jaws come together, describing a downward arc or a digging action in the process. When the two shells have closed, the bucket is filled to the brim with ore. The 275-horse-power motor of the walking-beam hoist now comes into action once more to elevate the bucket-leg, and lift the laden bucket clear of the boat. The moment the bucket has cleared the hatchway, the 120-horse-power motor of the trolley asserts itself, and the trolley retreats along its track until the bucket, still rising, is brought over the main hopper placed between the girders in the main framework. The bucket is now opened by means of its gearing to release its capacious mouthful of ore into the hopper. The trolley, which has scarcely stopped, is reversed, and is again moving towards the front of the machine; the bucket-leg is maintained in its elevated position by the grip of the brake mechanism.



FOUR AUTOMATIC ELECTRICALLY OPERATED HULETT ORE UNLOADERS AT WORK ON A VESSEL AT THE PITTSBURG AND CONNEAUT DOCK CO.'S WHARF.

Approaching the hatchway, the brake upon the walking-beam hoisting mechanism is released, the bucket descends into the hold for a fresh charge, and the cycle of operations is repeated.

Meanwhile the ore which has been emptied into the main hopper is being passed through a further phase of movement. It is dropped into the larry hopper; the main hopper gates are opened by the 100-horse-power motor, the larry having been brought to the point immediately beneath the hopper gates. The larry hopper charged, its 150-horse-power travelling motor is set in motion, and by it



FROM ORE CARRIER TO STORAGE PILE.

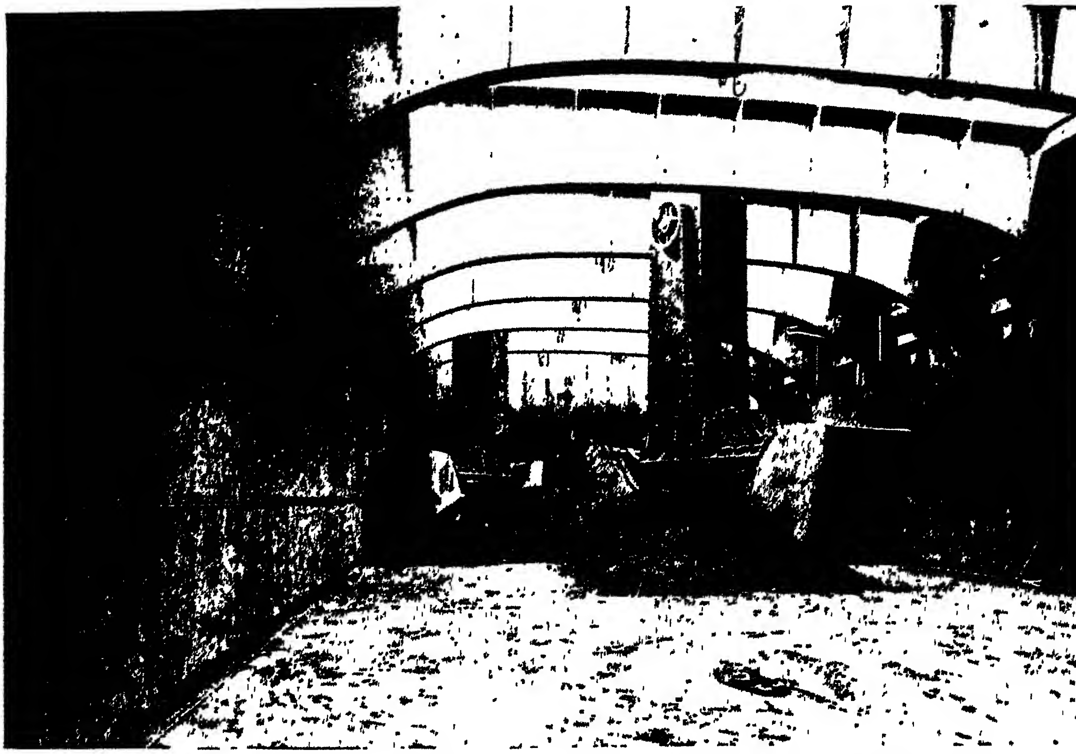
On the left the huge piles of ore, stacked by the four unloaders shown at work, are being transferred by the rehandling bridge to the main storage bin in the centre by the 15-ton bucket which is shooting its load.

hauled up the inclined plane until it is brought over the empty railway car below, or the storage bin under the cantilever of the machine. The 40-horse-power motor actuating the larry hopper gates is switched in, the gates open, and the load is discharged, either wholly or partially, as desired. This function completed, the larry returns to the main hopper to receive another charge of ore. As the larry hopper is furnished with scales by which the contents are weighed accurately and the weight recorded, a railway vehicle can be loaded to its full capacity, and the quantity of ore deposited by the unloader automatically recorded. All further weighing of the load is thus avoided. Similarly, a record of the tonnage discharged by the larry hopper into the storage bin is secured. In this way a complete check of the cargo brought in by the steamer is obtained.

Some of the unloading performances which have been placed on record are certainly amazing, and reveal what can be accomplished by means of this equipment. The Wellman-Seaver-Morgan Company, the builders, installed a battery of seven machines, side by side, upon the dock at Conneaut, Ohio, for the United States Steel Corporation. The ore steamer *W. P. Palmer*, with 11,000 tons of ore aboard, drew alongside to make fast. As the mooring ropes were being secured the seven machines came ambling along to take up their positions before as many hatchways. The ore was withdrawn from the boat and discharged direct into the railway vehicles for immediate conveyance to the furnaces, and the whole of the 11,000 tons was transferred from ship to rail in 2 hours 58 minutes.

Another remarkable performance

was recorded at Ashtabula, where there are eight of these machines, each of 15 tons capacity. Seven ore boats came in, bearing a total cargo of 76,000 tons, upon which it was imperative to make an energetic unloading attack. This was prosecuted credible, but it must be remembered that the complete cycle of operations, that is the descent of the bucket into the hold, filling, withdrawal, retreat of trolley to permit discharge into main hopper and re-descent of the bucket into the hold only takes



BUCKETS OF UNLOADERS CLEARING UP THE FLOOR OF AN ORE CARRIER'S HOLD.
These buckets measure 24½ feet from lip to lip when fully distended as shown, and hold 17 tons. In the bottom of the leg is the cabin from which all unloading movements are controlled. The operator rides up and down, and to and fro, during the discharging process; each trip occupies 50 seconds.

so successfully by the eight appliances that the whole of the 76,000 tons was moved in 24 hours, no less than 70,000 tons being cleared in 22 hours. At other ports it is by no means uncommon for four machines, working simultaneously upon boats ranging up to 13,000 tons capacity, to complete their task in 3 hours 25 minutes. At Cleveland, where the Ohio and Western Pennsylvania Dock Co. has four 17-ton unloaders of this type in service, the mechanically discharging phalanx emptied 11,083 tons of ore from the hold of the steamer *James A. Farrel* in 215 minutes.

Such rapid working appears almost in-

50 seconds. In other words, steamers can be unloaded at the rate of 17 tons—one mouthful of ore—in less than a minute by each machine employed. Furthermore, it must be borne in mind that the movement cycle of the larry—charging, weighing, discharging and return—is synchronous with that of the bucket; the latter cannot run away from the former and be brought to a standstill because the work of the second part of the machine has become congested with material or overtaxed. It is the synchrony of the operations of the two essential elements which contributes to the striking efficiency of the whole.

Under such rapid unloading conditions, and by the aid of such perfect electro-mechanical movement and control, it is not surprising to learn that operating costs have been reduced to an insignificant figure. According to records which have been collected over a long period, the cost of unloading iron ore in this manner from the holds of steamers ranges from 1·25d. to 2·25d. per ton. This sum is inclusive of superintendence, labour, repairs, and materials on the machines as well as the consumption of current for power and light.

Low Cost of Unloading Ore

The necessity for the steel-works to accumulate sufficiently big stocks of ore during the summer season, to tide them over the winter period when lake navigation is impossible, has involved the provision of huge storage yards. These are equipped with a plant which may be described as the logical electro-mechanical corollary to the unloader. It is an independent unit and quite distinct from the ore-discharging apparatus, but has been introduced as a supplementary unit thereto, and capable of working at a comparative high speed, so that it may keep pace with the unloader. The larry hopper of the last-named, when the ore is designed for storage, shoots its load into the storage bin spanned by the cantilever. This is where the duty of the unloader is completed, as previously explained, and the ore is moved therefrom to the main storage pile by the auxiliary apparatus.

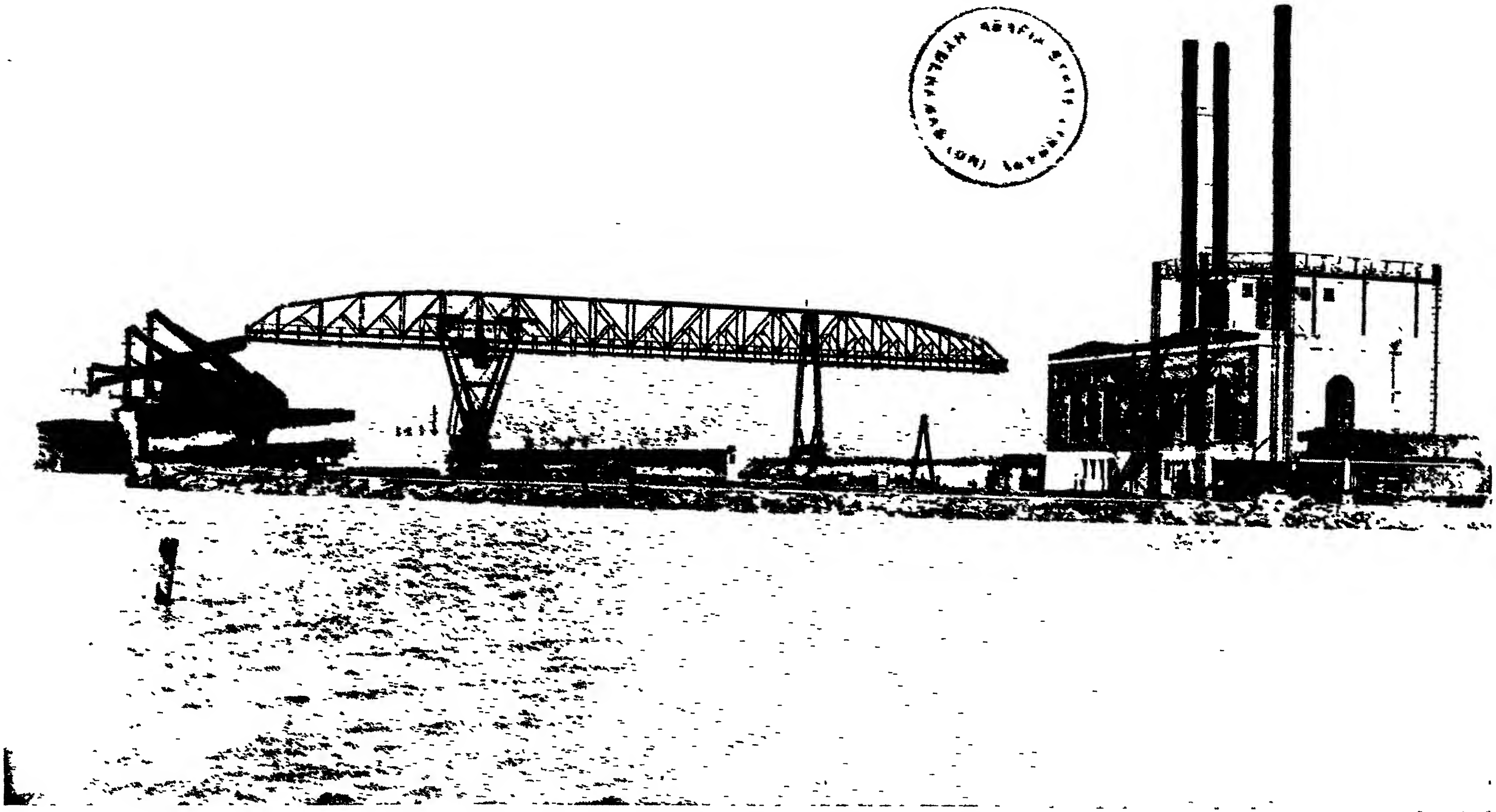
This supplementary appliance is described as a stocking, rehandling, or ore bridge. On either side of the main storage pile is a massive concrete wall forming the foundation for the travelling cantilever bridge. At the unloader end there is the main tower, mounted upon a multiwheeled trolley and carrying the travelling drive and motor equipment. Upon the opposite wall is a shear leg also mounted upon a multiwheeled trolley. At each end, the stocking bridge has an overhanging section; that on the dock side is designed to secure command across the full width of the unloader storage bin. Some of these bridges are of imposing dimensions; the largest yet erected is that installed by the Wellman-Seaver-Morgan Company, on Whiskey Island, Cleveland, for the Pennsylvania Railroad Company. This bridge is 612 feet from end to end, and it commands an ore storage bin capable of holding more than 1,000,000 tons.

The Stocking Bridge

The under side of the bridge forms a track along which runs a trolley equipped with the motors for propulsion and the operation of the ore bucket, as well as forming a cabin for the operator. The capacity of the bucket—the largest being of 15 tons—varies according to the requirements of the traffic. In conjunction with the unloader the stocking bridge renders the ore-discharging equipment very complete. Although most extensively employed for the handling of ore it is freely used for the unloading of coal; one of the most successful installations for this purpose is that erected at the Island Dock of the Canadian Pacific Railway at Fort William, Ontario.

Also Unloads Coal

This installation comprises two 8-ton Wellman-Seaver-Morgan unloaders, and a 9-ton stocking bridge. The bridge has a total span of 518 feet 10½ inches; the central span, between the main tower and opposite shear leg, is 285 feet; while the total length of the travel of the trolley with its 9-ton bucket is 485 feet 8 inches. From the trolley track to ground-level is 69 feet, and the coal can be piled to a height of 46 feet. This installation has proved highly successful, and, incidentally, it may be remarked, accomplished one of the most remarkable unloading performances yet recorded. The lake steamer



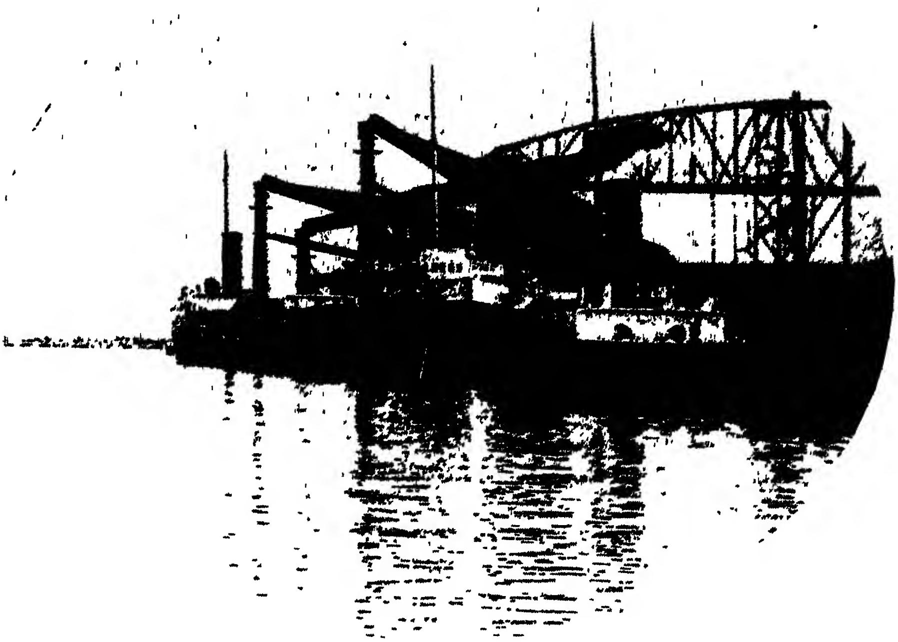
THE LARGEST ORE-HANDLING BRIDGE IN THE WORLD.

It measures 612 feet in length, is equipped with a 15-ton bucket, and serves a storage bin holding more than 1,000,000 tons. Unloaders engaged in discharging a vessel are seen on the left. This plant was installed for the Pennsylvania Railroad Company at Whiskey Island, Cleveland, Ohio.

W. P. Snyder, Jr., drew alongside with 14,576 tons of coal, and the two 8-ton unloaders emptied the vessel in 19 hours.

With such remarkably rapid and wonderful time- and labour-saving appliances it is not surprising that the ore traffic of the Great Lakes has grown to huge proportions. The machines may be ponderous and heavy, but owing to the simplicity of their design and control, coupled with sturdy construction, the liability to derangement is slender; while the maintenance charges are low. The capacity of the bucket and its extensive range of movement, coupled with perfect balancing and its positive guidance through the hatches, thereby eliminating risk of damage to either ship or machine, constitute distinct advantages.

With this plant it is possible to remove 97 per cent. of the total cargo of an ore carrier without the aid of shovellers. These are brought into service only in the closing stages to pile the remaining 3 per cent. of ore distributed in a thin layer upon the hold of the vessel into small heaps for the efficient charging of the bucket. Owing to their high capacity it is possible to reduce the number of units to the minimum. The fact that only three skilled men are required for the control of each machine, constitutes a further prominent advantage. Incidentally the plant supplies a graphic illustration of what can be accomplished by harnessing electricity for the actuation of a mechanical appliance. So successful have these unloaders proved in practice that more than fifty of them have been installed at the ore-discharging ports of the Great Lakes.



FOUR AUTOMATIC ELECTRICALLY OPERATED HULETT ORE UNLOADERS AT ASHTABULA.

Telephoning without a Mouth Transmitter

AN INGENIOUS INSTRUMENT WHICH CARRIES THE TRANSMITTING AND RECEIVING DIAPHRAGM IN ONE CONTAINER

SOME twenty-five years ago a young British engineer was attracted to that highly specialized branch of electrical science—telephony. His attention had been drawn to a field in which such communication was urgently required. Many engineers had grappled with the issue but without success. Their failures did not occasion surprise, because the difficulties which had to be overcome were admitted to be particularly exasperating.

The very complexity of the problem attracted this young engineer, and at last he evolved a telephone which, in the opinion of those most competent to form an opinion, fulfilled the desired purpose with complete satisfaction. He disposed of his idea in its entirety for £10. The purchaser completed a remarkably profitable bargain, because that investment has returned thousands of pounds, the invention in question having been adopted in its distinctive province throughout the world, and has not yet been superseded for its particular duty.

The inventor, Robert L. Murray, for a quarter of a century has persistently and energetically attacked telephone problems one after another. Needless to say, the commercial success attending his first venture did not fail to make an enduring impression upon him. It was his first and last disposal of a telephonic patent for a bagatelle. "But," as he humorously remarks, when referring to the incident, "even a Scotsman must buy his experience!"

In the course of his laboratory researches and investigations for possible new avenues of telephonic application, Mr. Murray was brought face to face with a situation in which communication was imperatively urgent. This was in the colliery overtaken by disaster. No effort is spared by the coal-mining interests and their personnel to maintain efficient rescue organizations, and to use the most up to date appliances

MINE-RESCUE LARYNGAPHONE IN OPERATION.
Showing the attachment of the telephone to the larynx below the gas-mask, and the tubes extending to the ears, with the connexion to the cable wound on the reel in the battery box.

to facilitate the succour of unfortunate miners trapped underground. But Mr. Murray, as the result of his intimate association with the coal-mining industry, became impressed by one distinct handicap attending mine-rescue operations. The system of communication between the man who ventured into the dark depths of the stricken area to render aid, and his base, was very primitive.

The base, which may be compared with an advanced dressing-station upon the battlefield, seeing that it is the point at which stretchers, doctors, and ambulance facilities are concentrated, is pushed as near the fringe of the danger zone as is safely practicable. From this point the rescuer, after donning his mask, goes forward. He may either be given a time limit in which to complete his journey of exploration—should he not return upon the expiration of this interval, another man is sent off to search for him—or be equipped with an ordinary telephone outfit. The wire is coiled upon a drum strapped knapsack fashion to his back; this line also forms an electric bell circuit. This telephone can work only in one direction; the man at the base can talk but the rescuer cannot reply because his mouth is covered by his respiratory apparatus. Replies are therefore confined to electric bell signals in accordance with a prearranged code, to furnish the base with such specific information as it desires.

Inadequacy of Ordinary Telephone

There are many objections to such a system. The wire-drum strapped to the man's back handicaps his movements, if it does not become an actual source of danger. He may have to bend low to squeeze through a narrow passage, and the projecting reel may foul the roof. Reliance upon a code is likely to be distracting and lead to confusion or mistake.

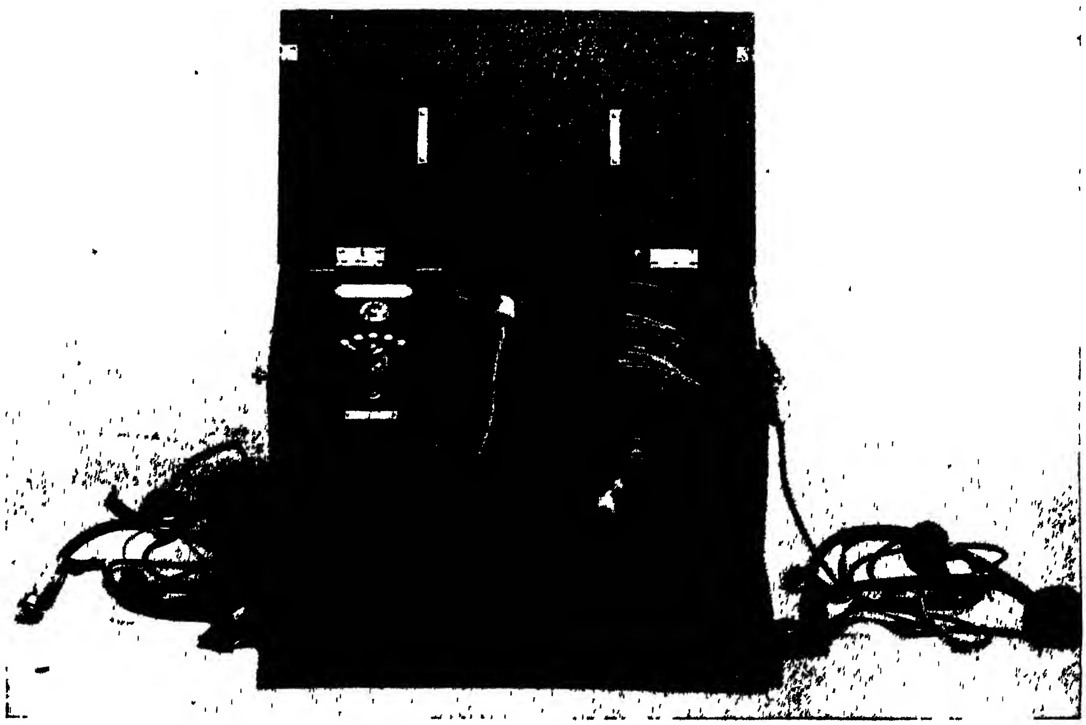
The telephone engineer realized that, if telephonic conversation could only be conducted in both directions with equal facility, the work of the rescuer and the general succouring operations would be simplified, expedited, and rendered much safer. The problem was to invest the rescuer with the power to converse. The respiratory apparatus was the stumbling block. The nostrils are closed by a clamp, thus compelling breathing through the mouth; the same atmosphere is used over and over again; each exhalation is purified and regenerated with oxygen before reinhalation. The mouthpiece is fitted in the form of a gag to prevent "after-damp" penetrating to the lungs. In view of these conditions the introduction of a mouth transmitter was wholly impracticable.

Although the problem was as perplexing as one could desire, Mr. Murray set to work upon its solution. The possibility of being able to collect the vibrations set up by the vocal cords, and in such a way as to allow the transmitter to be applied elsewhere than to the mouth, made distinct appeal to him. For twelve months he grappled with the problem, often shutting himself in the laboratory of the Telephone Manufacturing Company, Limited, to which he is advisory engineer, for a week at a time, threatening dire penalties upon all and sundry who ventured to disturb him. He had conceived a novel idea—something quite new to telephonic science, and he was determined to translate it into practice if humanly possible; but its perfection involved the handling of extremely feeble and delicate electric currents, and wrestling with sounds which were scarcely audible, so that unfettered and undisturbed concentration upon the quest was essential.

An Indefatigable Inventor

In setting out to achieve his purpose, the engineer recognized that the combination of the transmitter and receiver in a single element constituted the crux of the whole problem. Now, two diaphragms are involved: the one on the transmitter converting sound into electrical waves, the

other in the receiver retranslating the electrical into the original sound waves. Obviously, the two diaphragms must vibrate in dead synchrony, and this was where exasperating trouble was experienced. The moment the transmitting diaphragm was set in vibration that of the receiver would vibrate in sympathy, setting up a disconcerting whistle to the obliteration of all other sounds. Mr. Murray, however, persisted in his investigations, and finally, after many months of sustained labour, he succeeded in reproducing, for the first time in the history of the telephone, a practical complete unit carrying the transmitting and receiving diaphragm in a single container.



PORTABLE LARYNGAPHONE DESIGNED FOR MINE-RESCUE WORK.

On the left is the laryngaphone worn by the operator at the base; on the right that worn by the rescuer equipped with a gas-mask. The box carries a reel on which is coiled 100 yards of cable, and to which further lengths can be connected if desired. At the left of the box are shown a sound-amplifying adjuster, an electric pilot-lamp indicating maintenance of circuit, and a code signalling button.

This telephone is extremely simple. It has no new essentials. The details of the familiar instrument have merely been rearranged scientifically, but along lines which had never previously been considered feasible. There is the carbon transmitter and the receiver operating upon a combined electro-magnetic principle. Having satisfactorily surmounted the problem of combining the two units into a single element, the inventor advanced his idea to the succeeding stage. He set out to abandon the mouthpiece. This represented a revolutionary step of a decisive character because one naturally asks: " How is it possible to telephone without speaking into the transmitter ? "

Now the sounds we utter, whether they be musical notes, words, or ejaculations, are merely the audible signs of a specific physical action taking place within the throat. They are vibrations set up by the movement of the vocal organ or larynx. Accordingly, the inventor reasoned,

"Why should not the transmitter be able to catch the vibrations at the actual point where they are set up?" He decided to ascertain if such were feasible —and triumphed. He discovered that when the transmitter which he had designed was held tightly against the larynx, and the sounds were uttered in the usual manner, the device caught and transmitted them just as readily as the ordinary transmitter held before the mouth.

This discovery brought his idea to the verge of complete fulfilment. The next step was to obtain perfect articulation. For a long time little or no headway was recorded; the reproduced sounds persisted in being unintelligible. Even the familiar "Hello!" would resolve itself into a sound reminiscent of a sneeze or a deep cough according to the tuning of the device. By careful fashioning and gradual progressive adjustment of the integral parts the jumble of noises was slowly unravelled to assume intelligibility.

Yet the objective had not been completely attained. Speaking under normal conditions is vastly dissimilar from conversing with the mouth obstructed, as in the case of the mine-rescuer, by a gas-mask. The insertion of the gag in the mouth renders it extremely difficult to give the correct articulation to the labials, dentals and sibilants, for the simple reason that the free movement of the lips, teeth and tongue is impeded, while the natural resonance of the roof of the mouth is also disturbed. To meet this situation the inventor was compelled to modify the components and their finer adjustments.

HOW THE LARYNGAPHONE IS WORN BY THE MINE-RESCUER
Showing the telephone held by the neck-strap upon the larynx, and detached from the gas-helmet, with tubes extending to the ear-caps. The telephone, it will be observed, is no larger than a wrist-watch, and the method of attachment leaves both hands free

This invention, described as the "Laryngaphone," from the fact that it is dependent for its operation upon direct contact with the larynx, the seat of vibration, represents as distinct an advance upon the familiar telephonic system as did Bell's invention upon the old-fashioned speaking-tube. We all know how the conventional instrument will pick up and transmit all sounds coming within its range with exasperating indiscrimination. If one is talking amid this babel of noise all the foreign sounds will be carried across the wire.

With the laryngaphone there is no possibility of any extraneous noises entering the circuit. The essential elements are carried in an air-tight and water-tight case which rests lightly upon the larynx. It can only pick up the sound vibrations emitted by the vocal cords, because it is not exposed to surrounding sound interference as is the ordinary mouthpiece, which is not used as a contact. Similarly, owing to the system of conducting the sounds to the ear, it is impossible for the listener to suffer the slightest disturbance from investing noises, or to experience any difficulty in hearing the message coming across the wire. He may be standing beside a blaring siren or a screeching buzz-saw, but neither sound will impinge upon his aural organ to confuse the conversation which is being deliberately conveyed to him.

As may be surmised, a new idea has been incorporated to transmit the sounds coming across the wire to the brain. As the receiver forms part of the complete apparatus which is rested upon the larynx, obviously the ear-cap must be of new design. It comprises a light, conveniently shaped disk of ebonite fitted with a delicate valve. A cap is applied to each ear, and from each a thin flexible tube extends to the combined transmitter and receiver. The vibration of the receiving diaphragm sets up pulsations of air waves, corresponding to the sound vibrations communicated by the diaphragm, and these travel through the connecting tubes to the ear to be conveyed direct to the brain. Some may think, perhaps, that owing to the connexion of the ear to the telephone in a closed circuit, the ear-drum would suffer inconvenience, if not actual injury, from the rapid air vibrations set up, but this danger is eliminated by delicate valves. These act as an automatic vent and air balance, maintaining the equilibrium of the air-pressure upon the sensitive ear-drums at just as constant a level as when the ear is exposed. So perfect is the action of these valves that the wax in the ear does not suffer the slightest disturbance.

COMMERCIAL LARYNGAPHONE WITH COMBINED TELEPHONE AND EAR-CAP.

The instrument is mounted upon a swivelling arm to allow easy adjustment to the larynx, while the receiver lies flat against the ear.

In its latest form the laryngaphone is a wonderful and extremely sensitive device. It is no larger than a wrist-watch, while its weight is insignificant. It is merely laid upon the larynx, being held in position by a strap carried loosely round the neck. No pressure whatever is applied; the lighter the contact the more perfect the communication. One might be disposed to imagine that the imposition of such a device upon the vocal organ would be likely to inflict injury, because the larynx is generally maintained to be extremely delicate; but one would be surprised at its enormous strength and the power of its muscles. The organ suffers neither fatigue nor strain. Mine-rescuers, who have worn the telephone for hours at a stretch, declare that less strain

is imposed with this device than by conversation with the familiar instrument. Hoarseness is quite unknown.

The connexion between the telephone and the circuit is of a flexible character.

Laryngaphone Easily Detached

From the lower rim of the device extends a short length of flexible wire terminating in a plug. This is clipped into the corresponding socket of the circuit. The fitting is such that the connexion can be broken instantly by a slight jerk, leaving the operator free and with the telephone still in position, ready for the resumption of communication directly the circuit is restored. If preferred the laryngaphone can be detached; it is only necessary to release the neck-strap; it then slips over the head and can be folded up and stowed in the pocket. One advantage accruing from the system is that the hands are left entirely free. Of course, when the system is applied to the familiar telephone circuit the head attachment is unnecessary.

The mine-rescue apparatus weighs only 36 lb. complete, and from the "safety" point of view it meets the situation very effectively. There is a small box which forms the base-station, set up as near the fringe of the danger zone as circumstances will permit. This box carries two or more sets of laryngaphones, one for the base-operator, and one or more for the rescuer or rescuers. It also contains a small drum upon which is coiled 100 yards of thin well-insulated cable. The equipment is completed with the battery set, an ingenious indicating apparatus, an amplifier and an emergency signalling device.

After donning his respiratory apparatus the rescuer assumes his laryngaphone and couples it up to the drum-cable by the plug and socket connexion. The base-operator also fits his telephone in place and connects up in a similar manner, the two men now being in communication, via the cable. The rescuer moves off into the danger zone, the cable unwinding and trailing behind him. The line is open and both men can converse freely. The base-operator is kept informed of the maintenance of the line by a small pilot electric light on the battery box lid. Normally this glows dimly, but should the line suffer injury, as by a fall of the roof after the rescuer has passed, the lamp burns more brightly. This warns the base-operator to test the line. Should there be an interruption, the base-operator at once endeavours to get through to the rescuer by means of the emergency signalling device. This is a button which when depressed in accordance with the Morse, or any other prearranged code, enables the rescuer to be apprised by dot and dash sound signals in his telephone that further conversation is impossible. It also warns him that he had better return, and in so doing keep a sharp look out for obstructions.

An Effective Emergency Device

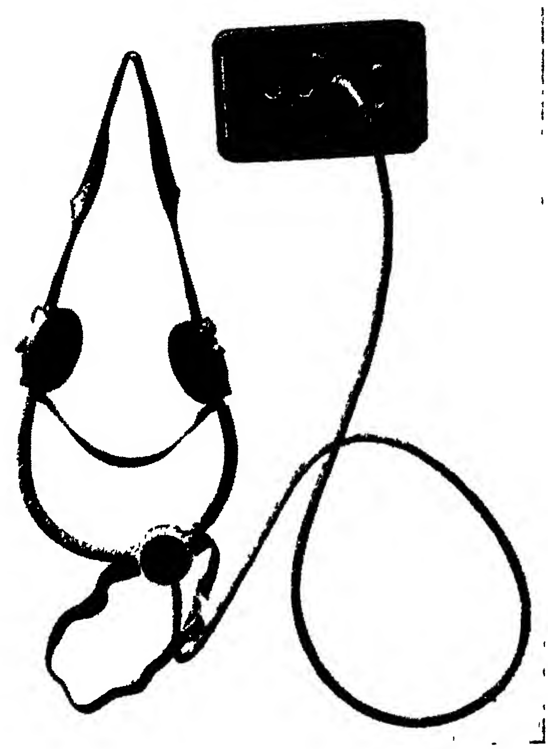
By the emergency device it is possible to get information through to the rescuer even when the line is severed; an electric impulse, such as a dot or dash, will probably traverse a break which is impassable by the human voice. Should circumstances compel the rescuer to beat a precipitate retreat he need not worry about his cable. He merely jerks his plug clear of the line socket, leaving him free to hurry back without danger of being hampered in his movements, which would be the case if he were permanently connected to the cable. The loss of the latter is insignificant; a line is seldom used more than once in such work. Although the drum carries only 100 yards of line, further drums can be introduced as desired, by plug and socket couplings, and in this manner a mile or more of cable can be paid out. As a rule, however, rescue operations are conducted within a relatively short distance of the mobile base in the mine.

Similar arrangements have been introduced to facilitate the operations of firemen

and salvage workers entering a poisonous atmosphere in their protective gas-helmets. It is equally serviceable for any industry demanding the penetration of noxious fumes. Under present conditions such work is hazardous to the men engaged because they have no satisfactory means of communicating from the danger zone to the station outside. The ability to maintain conversation in *both* directions constitutes the outstanding attraction of this telephonic development. Already it has been adopted by mine-rescue and other organizations, and is giving the utmost satisfaction. Experience has revealed one requirement. This is the advisability of talking as much as possible from the throat when wearing a mask; clearer articulation is thus assured. This precaution, however, is merely dictated by the extreme difficulty encountered, when the mouthpiece of the mask is in position, to move the lips, teeth and tongue in the manner necessary to give distinct pronunciation.

The laryngaphone also promises to revolutionize subaqueous work. The present communicating equipment of the diver has many shortcomings. The hissing sound arising from the forced circulation of air from the pump to the helmet renders speaking and listening extremely difficult. It is impossible for two or more divers working together under water, as upon wreck salvaging or constructional operations, to converse with one another. With the laryngaphone these disabilities are removed. The station on board the salvage vessel is broadly similar to that designed for mine-rescue work, but it has one valuable addition—a switch-board of the semi-automatic indicator type with central battery. Consequently the requirements of any number of divers working below can be fulfilled. Each diver's wire is carried to the switch-board via his air-line.

The operation of the switch-board follows novel lines; its visual indicators also act as switches. When a diver signals to the surface, the impulse not only drops the indicator of his line but switches his speaking circuit through to the attendant. The line is automatically opened and conversation is possible without any



THE AIRMAN'S LARYNGAPHONE

This has proved to be the only efficient instrument for use in the air. It shuts out the noise of the motor. This illustration shows the telephone and adjustable neck-strap, ear-caps with connecting tubes, and switch-board for communication between pilot and passenger or observer.

further preliminary. On the other hand, should the attendant wish to speak to the diver he merely drops the corresponding indicator upon the switch-board by depressing the switch control connected to it, and he is at once through to the diver.

Should one diver wish to converse with a colleague working on the sea-bed with him, he merely signals the attendant in the usual manner and intimates his request. The attendant depresses the second diver's switch and so brings the two men working

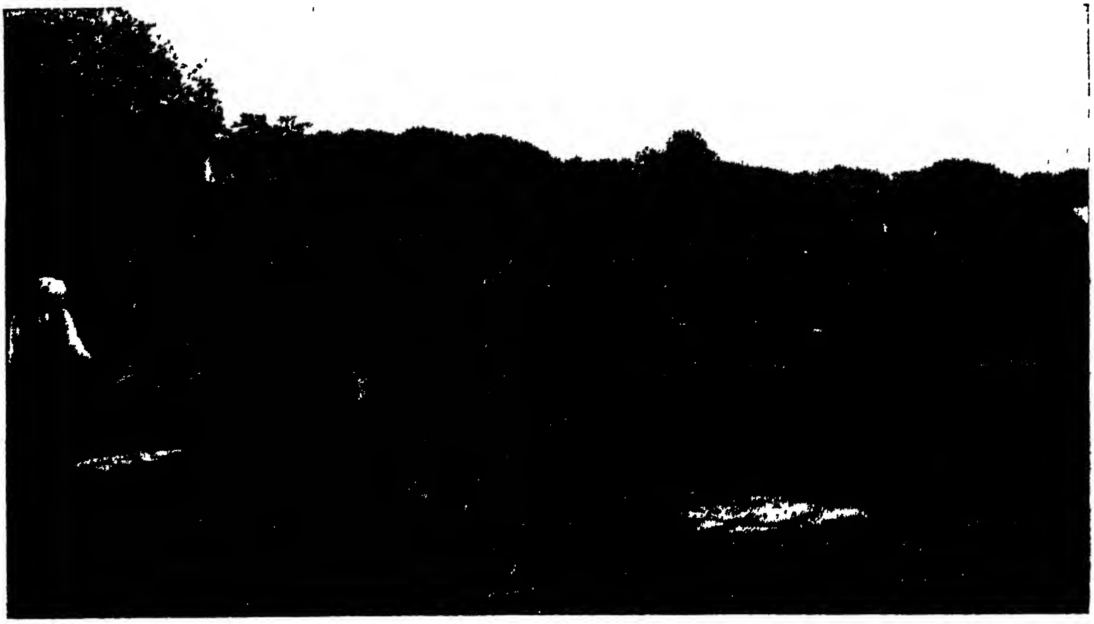
under water, and invisible to one another, into direct conversation. Another feature of the switch-board system also deserves mention. The attendant may suddenly consider it advisable to summon all the divers to the surface immediately, as for instance upon the approach of bad weather. He merely depresses a special or emergency button which throws *all* the line switches and opens the whole of the lines simultaneously, so that the message reaches each diver at the same time. The novel switch with which the diver is provided dispenses entirely with hand action. Fitted to the upper edge of his laryngaphone is a small signal switch. to actuate which, and thus to communicate with the switch-board, the diver merely has to open his mouth. His lower jaw, in falling, depresses the switch on the instrument fitted to his larynx and the switch-board indicator drops.

INDUSTRIAL LARYNGAPHONE FOR USE IN BOILER WORKS AND OTHER NOISY SITUATIONS.

It is worn attached to the head, as shown, ready for instant conversation, but leaving the person free to pursue his ordinary duties.

Another ingenious use is designed for the airman. The aviator is engulfed in the deafening din of the open exhausts of his engine, and so finds it almost impossible to maintain free conversation. The ordinary telephone does not meet the situation owing to the transmitter picking up the motor noises as readily as the human voice. With the laryngaphone the roar of the motor is eliminated and by a simple modification. Beneath the ear-flaps of the helmet the unobtrusive ear-pieces, connected by the tube to the telephone, are permanently fitted, although they can be readily detached. The ear-caps are ventilated, the valves, to which reference has been made, maintaining the air-pressure upon the drum of the ear equably under all conditions. This ingenious apparatus, it may also be pointed out, is eminently useful for service in places where exceptional ear-splitting noises prevail such as boiler-works, steel-working shops, gun-firing test grounds and so forth.

Other applications are obvious. It can be installed between the guard at the rear of the train and the driver upon the foot-plate. Aboard ship, when the noise of the storm renders all other means of spoken communication difficult and uncertain, instructions can be issued to any and every station in the confident knowledge that the message will be heard clearly and distinctly, and thus render the risk of misconstruction extremely remote. It is necessary to emphasize one point. Although the instrument is applied to the larynx, instead of being held immediately in front of the mouth, it is just as necessary to give audible enunciation. One has to speak no louder, if as loud, but the laryngaphone will no more transmit a whisper than will the ordinary telephone.



CLEARING TREE STUMPS BY ELECTRIC BLASTING.
The explosive charges are tamped in holes angularly bored into the stump and are connected up in series with the low-tension exploder.

Little Currents which do Big Work

THE ELECTRIC SPARK AS AN OPERATOR OF EXPLOSIVES

WHEN surveying the vast field of human endeavour one is apt to dwell only upon the grandiose. One cannot resist being impressed by the apparent facility with which the engineer drives his way through the most forbidding of barriers, tames the mighty waterfall, carves a path for the railway, tears a passage for ships, and sets out to hurl defiance at the storm. In the electrical field one is amazed at the enormous power of the current which is produced and dispatched over vast distances across a seemingly slender aerial conductor.

In the majority of instances the spectacular has been achieved by recourse to the very lowest end of the electric power scale. To secure the fulfilment of his daring schemes the engineer freely employs electric currents so feeble that, when applied to the human body, they almost escape detection. Yet, therewith terrific slumbering forces are roused to tear great gashes in the beds of roaring rivers, to remove mountains, and to drive gloomy caverns through the granite.

It sounds paradoxical, but it is nevertheless true. The most serviceable handmaid of the modern engineer is the explosive. By the weak electric current the quiescent chemicals entering into the constitution of this agent can be stirred into most devastating activity. Nowadays, the detonation of an explosive charge, whether it be large or small, by the aid of electricity, is accepted as being the most scientific, effective, and safe means yet devised, and

THE BLAST.
The charges inserted in the tree stumps, and connected in series with the exploder, are fired simultaneously.

is consequently the method most extensively favoured. Other means of firing the blast are freely employed, but it is electricity which holds sway, and, in certain circumstances, as, for instance, the simultaneous firing of a number of shots, is the only system capable of efficient use.

Electric blasting is conducted either along high-tension or low-tension lines. This issue is governed, in the main, by local meteorological conditions. In Europe, where extreme climatic changes do not prevail, the high-tension system is freely employed. In this instance it is the generation of the electric spark which accomplishes the desired end. The fuse is a sensitive chemical composition in which the ends of two naked wires, spaced a specific distance apart, are embedded. These wires extend from the cartridge to the cable connected to the electric generator or exploder. When the impulse is sent across the wires its uneventful flow is disputed by the gap in the fuse. It jumps this interruption in the conductor, producing a spark which suffices to ignite the sensitive composition lying in its path, and so brings about the detonation of the charge. As this system is a combination of the electric spark and sensitive chemicals, the detonator is sometimes described as a chemical fuse or fusee. The keeping qualities of this detonator are not of the highest order, and so it cannot be recommended for use in tropical climes or in countries where striking fluctuations in temperature prevail. Finally, there is an element of chance about the system. The electrical circuit in the detonator cannot possibly

be tested previously to ascertain if it is in working condition.

In the low-tension system no spark is produced to ignite the charge. The continuity of the electrical circuit through the combustible composition which forms the cartridge is preserved, but at the point where the conductor traverses the fuse a short length of bare, hair-like wire, preferably of platinum, is introduced to form a bridge between the two wires of the conductor proper. The chemical composition surrounding this bridge is also of a different character, and is known as a "flashing mixture." When the current is discharged across the wire and reaches the bridge the latter acts as a resistance. The intervening length of fine wire becomes heated to incandescence, and so ignites the flashing mixture by which it is surrounded, which, in turn, fires the detonator and ultimately the explosive charge to which it is connected.

Low-tension detonation is more extensively employed owing to its efficiency and greater safety. The detonators, from the character of their composition, are able to withstand the rigours of transport, and can be kept in storage for a much longer period without deteriorating than their high-tension consorts. Finally, and this is a vital point, the detonators can be tested by means of the galvanometer before firing, thereby satisfying the man in charge of the blast that the electrical circuit is in perfect working order.

The method of testing a low-tension fuse, as advocated by Nobel Industries, is very simple, and may be conducted in perfect safety with the special device which has been evolved for the purpose. The fuse-wires, with which the detonator is supplied,

AFTER THE BLAST

Stumps disrupted and torn from the soil with their roots. The disturbance of the earth is slight and local.

are bared at the outer ends, and the detonator to which they are attached lowered several inches into a special substantial iron pot. The bared ends of the two wires are then pressed firmly upon the two terminals of the galvanometer, one wire to each terminal; care is observed to prevent the ends of the wires from coming into contact with one another during the test. If the detonator be perfectly sound the needle moves; if defective it remains stationary.

The apparatus to conduct the blasting operation is simple. The exploder, or current generator, is contained in a small box and is actuated either by a trigger or handle. A well-designed robust machine is as reliable as a clock, and will render faithful service for years. A necessary adjunct is a length of flexible cable coiled upon a reel to serve as the connecting link between the exploder and the wires embedded in the fuse.

Blasting Operations made Simple

When all is ready for the blast, the explosive with its detonator having been satisfactorily tamped home, the man who is ready to fire the shot assumes authority. He first bares and cleans the ends of the fuse-wires and of the cable respectively, joins them together, and insulates the junction effectively to prevent short-circuiting, or the impulse taking a short cut to earth. He then retreats a safe distance, bearing his cable drum with him and uncoiling the cable meanwhile. The length of the latter, of course, must be sufficient to permit the man to gain a position beyond the effects of the blast. This varies according to the nature of the work and the quantity of explosive to be fired. Nowadays explosives are freely employed for a variety of purposes, including agriculture, wherein relatively small charges are used which may be fired from an open position, but even then there should be at least 80 to 100 yards between the blast and the shot-firer. When dealing with heavy operations more elaborate precautions must be observed.

Satisfied that all is clear, and that the danger zone has been evacuated, the shot-firer connects the ends of the cable on the drum to the terminals of the exploder, and screws the nuts well home to ensure perfect contacts. This is the final duty preliminary to the blast. The shot is fired by smartly moving the handle attached to the top or side of the exploder; this action generates the necessary electric impulse and launches it upon its journey.

An instant later small wreaths of dust are observed to creep from the face of the rock, or the surface of the ground, followed immediately by an upheaval; shafts of smoke, dust, and debris fly into the air. A moment later comes the dull sullen report of the explosion, followed by the rattle of disintegrated material. When the eruption has died down the operator disconnects the cable from the exploder and rewinds it upon its drum; the explosion has already brought about its severance from the fuse-wires.

Occasionally the fuse declines to respond to the effort of the electrical impulse. Then it is the duty of the man in charge to ascertain the reason. The misfire may be due to any of a number of causes, or to a combination of two or more. The detonator may be defective although, if the low-tension system is used, the operator should have satisfied himself upon this point before it was tamped home. The wires may have become twisted, resulting in an imperfect connexion, or the wire ends may not have been cleaned sufficiently. (Electricity is particularly exacting in matters pertaining to cleanliness.) The wires may even have become severed through some fortuitous incident, or have come into metallic contact through broken insulation, resulting in a dead short. Whatever the cause the blast is probably lost. A new hole should be drilled to permit the

In case of Misfire

introduction of another charge, and, in those countries where rigid regulations concerning blasting are in force, this procedure has to be adopted. It is extremely hazardous to attempt to rectify a mistake and to persuade a missed shot to fulfil its designed function.

When a number of shots are to be fired simultaneously, electricity must be employed, because this is the only means whereby all the detonators can be exploded at the self-same instant. Under the high-tension system parallel or direct-contact practice must be observed; the negative and positive wires of the cable are joined to the negative and positive wires of each fuse. With the low-tension system series connexion is followed. In this arrangement one wire of the cable is connected to one wire of the first fuse. The second wire of the fuse is led and connected to the first wire of the second fuse. The second wire of the latter is led to the first wire of the third fuse, the second wire of which is led to the first wire of the fourth fuse, and so on, until all the shots have thus been linked up. Then the second wire of the last fuse is connected to the second wire of the cable.

Advantages of Low-tension System

One feature of the low-tension system is that, after wiring has been completed, the shot-firer can test the electrical circuit. He has only to press the two reel-end wires upon the respective terminals of the galvanometer, and instantly the perfection of the connexions can be verified by the oscillation of the needle. If the latter refuses to move, then there is a fault in the electrical connexions. With the high-tension system, as already explained, such a proceeding is impossible, so that the latter may be said to belong to the hit-or-miss order, although, if the work be efficiently carried out, and the detonators have been carefully stored, they should respond to the action of the exploder. So far as Nobel practice is concerned the general rule is that high-tension connexion must be in parallel for multi-shot firing, and low-tension connexion in series; distinctive types of exploders are designed for the respective duties. But the low-tension system also permits the employment of parallel connexion, only in this instance a third form of exploder, belonging to what is known as the "twist" type, must be used.

Dangers to Navigation Removed

Electricity is the force which permits coal to be brought to our homes, carries railways through towering mountain barriers, demolishes obsolete structures, obliterates menaces to industry, and contributes to the safe navigation of the seas and rivers of the world. For many centuries the waters of the East River and Long Island Sound washing the Island of Manhattan, upon which stands the city of New York, were extremely perilous. A mass of rocks straggled across the channel, churned the water into rapids, and set up vicious currents. It is estimated that one out of every fifty passing craft fouled those wicked teeth. So intensely was the spot dreaded by navigators that it became known as Hell Gate.

Repeated efforts were made to remove the obstruction, but to little purpose. Finally in 1885 it was decided to make a massed attack upon the menace. For a round twelve months the turbulent spot swarmed with "rock-hogs," moiling and toiling, driving tunnels through the jagged mass. Some four miles of galleries were drilled in all directions and loaded with big charges of dynamite. These were connected up to an electric wire network and led to a single exploder. From a point a safe distance away, the pressure of the trigger let loose the cyclopean force stored in the dynamite, and the whole of the rock, sprawling over six acres, was torn from its anchorage in the bed of the river and reduced to such small fragments as to be

By permission of Nobel Industries, Ltd

THE TERRIFIC FORCES RELEASED BY THE PASSAGE OF A TINY CURRENT.

A big electric blast in a Derbyshire limestone quarry The charge was 3,000 lb. fired in two headings, and the explosion was so tremendous that nearly 30,000 tons of limestone were brought down.

readily recoverable by dredgers. By one stroke the danger to navigation was removed; Hell Gate was no longer a terror to mariners, though its sinister name still remains.

Entrance to the port of San Francisco was similarly endangered by a huge oblong haunch of rock, lying right in the track of craft making the harbour by way of Alcatraz Island. The peril of Shag Rock, as it was called, was aggravated by its almost complete submergence at high tide; only an insignificant pinnacle was visible above the surface, although, at a depth of 30 feet, this fang joined the main hump, some 180 feet in length. In 1889 the Government, owing to the expansion of maritime traffic, was compelled to undertake the removal of the hump, although it was estimated that the work would occupy two years and cost some £40,000.

Removal of Shag Rock

A mast, 68 feet in height, was planted in a hole drilled in the protruding tooth, and to this was slung a platform, 180 feet long by 30 feet wide, a few feet above high water, and held in position by ropes led from the top of the mast; the disposition was such as to permit the platform to be rotated about its support. This platform carried a battery of machines operating the drills which were set to work boring into the hump below. Each hole was driven to a depth of 34 feet below low water and charged with explosive gelatine. Altogether 4,500 lb. of this agent were tamped home, and the wires from each shot were led to the cable to be attached to the exploder. This was carried upon a barge, which, at the appointed moment, was drawn to a point 6,000 feet away from the rock; all other marine traffic had been cleared for a mile around the danger spot. With a press, not much more than a child can exert, an electrical impulse was sent across the mile of cable. An instant later the bay presented the spectacle of being riven by an earthquake. A huge column of water, smoke and rock was hurled 1,000 feet into the air, to the accompaniment of a ferocious roar. Then the water around Shag Rock bubbled and seethed like a mighty cauldron, as the displaced water and fragments of rock fell back. The sea resumed its normal calm; the only remaining signs of the artificial subaqueous eruption were floating dead fish and the debris of the drilling platform which had been splintered by the blast. The hump had been blown to fragments to a minimum depth of 18 feet below low tide; the menace to shipping was no more.

Quarrying by Explosives

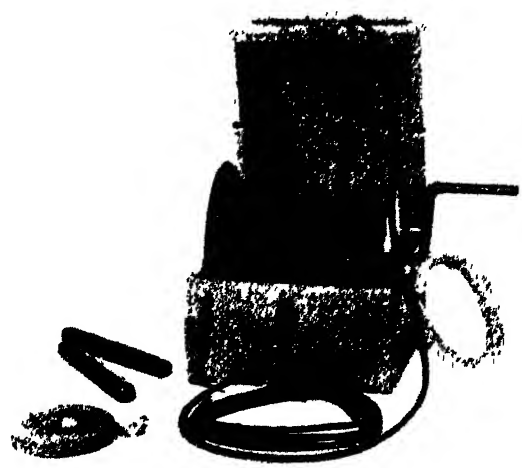
High explosives suited to commercial operations are invaluable in quarrying operations. The drilling of a few shot-holes in a cliff face, the insertion of a few score pounds of explosives, the coupling of the fuses to an exploder, and a dexterous twist of a handle will bring down thousands of tons of rock, for the most part sufficiently disintegrated to permit ready removal without further breaking except by such blows as can be delivered by a heavy hammer. At some quarries the mining of the desired commercial products is hampered by the presence of huge veins of useless rock. This is particularly noticeable in the Welsh slate quarries, where such faults or barriers of waste, known as dykes, at times become exceedingly formidable obstructions and sources of danger. The practice is to quarry round the dyke, recovering all the useful material, leaving in due course a lofty frowning cliff, or wall, projecting into the air, and perhaps at an alarming angle. In some instances these faults represent a dead mass of 160,000 to 300,000 tons. When the moment dawns for their removal the obstruction is tunnelled and charged with dynamite; from two to four tons of the explosive are distributed among the shot-holes. When the little electrical impulse is launched from the exploder the cliff is blown to smithereens.

Some of these dyke-blasts are of such a heavy nature that the whole aspect of the mountain side undergoes a startling transformation.

One of the most remarkable, even sensational, spectacles produced by such an insignificant impulse was the removal of the s.s. *Chatham* from the fairway of the Suez Canal. This vessel cleared an English port in August, 1905, with a mixed cargo, including 90 tons of Nobel explosives, and 160,000 detonators. While passing through the Canal, about 10 miles south of Port Said, she collided with another steamer, and, under the impact, caught fire. The captain, fearful of the consequences should the explosives become involved in the conflagration, sank his ship. The fire was extinguished, but another and equally grave menace was precipitated. Two cases of dynamite floated out of the hold, and upon examination were found to be exuding nitro-glycerine, one of the constituents of this agent. As the wrecked ship carried a heavy consignment of pig-iron it was feared that contact between the pig-iron and the nitro-glycerine would provoke a chemical friendship which might possibly extend to the bulk of the explosives, and assert itself in the most ebullient manner to the detriment of the Canal.

The wreck must be cleared at all hazards and with all speed. That was the official fiat; but it was an exceedingly delicate task, as a charge of 90 tons of explosive had never been fired in a single stroke up to this time. One of the foremost Nobel experts, with two trained workmen, were dispatched to the wreck to complete the work. Even the expert, as the result of his survey, became apprehensive. What would happen to the Canal when the dynamite and detonators went up? The Asiatic bank was not regarded with anxiety, but the African shore presented quite a different situation, because, on this side, the Canal is paralleled by a second channel supplying Port Said with fresh water; while the telephone, telegraph, and railway communications are also installed on this bank.

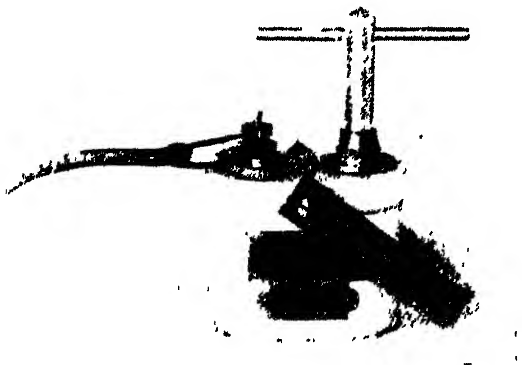
As a safety measure a deviation, 1,200 yards in length, in the freshwater canal was cut. A special firing charge of 250 lb. of blasting gelatine, with 50 lb. of dynamite, was prepared, enclosed in a canvas bag, and lowered into the hold to rest upon the 90 tons of explosives. Another charge of



REEL, CARRYING CABLE, FOR CONNECTING WIRES OF THE DETONATOR WITH THE EXPLODER.

150 lb. of blasting gelatine with 50 lb. of dynamite was similarly contrived, and lowered into the hold carrying the 160,000 detonators; the expert had decided to remove the danger by two explosions. Two electric detonator submarine fuses were attached to each firing charge. These four fuses were connected up in series, and the wires led to the telephone circuit of the Suez Canal Company, which was pressed into service to carry the little electric impulse from the exploder, to be actuated from a point 3½ miles lower down the Canal. The proportions of the blast rendered firing from a point nearer the wreck extremely hazardous.

Traffic was suspended and a military cordon prevented anyone approaching within six miles of the wreck. On the morning



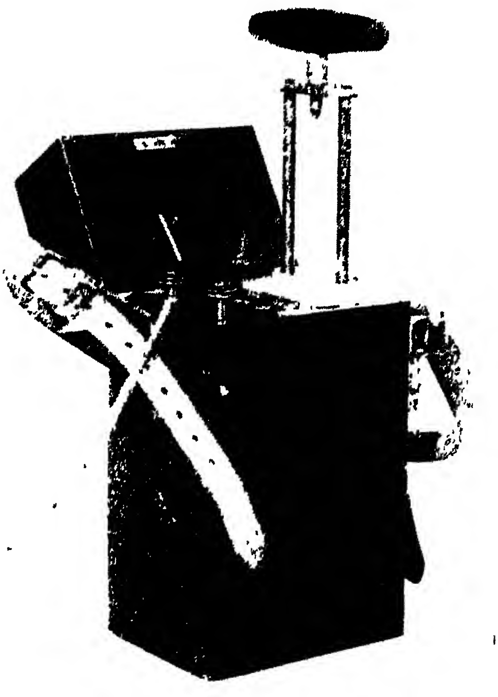
NOBEL MAGNETO EXPLODER OPERATED BY A HALF-TURN HANDLE

of September 28th, at 9.50, the expert received the signal "All Clear." He pushed home the lever of the exploder, and the impulse sped across the telephone wire to the wreck. Before the expert had withdrawn his hand he knew the impulse had got home, because he felt a slight tremor upon the lever—the first shock of the explosion transmitted through the earth. A huge column of water shot into the air to assume the form of a huge mushroom, and within 15 seconds of firing the shot the report of the blast reached the engineer.

Apprehensive of the effects wrought by such a terrific detonation, he hurried towards the wreck; but his misgivings proved to have been ill-founded. On the African side neither the railway nor the freshwater canal had been touched; only the telephone pole immediately opposite the wreck, to which the fuse-wires had been led, was affected—bent outwards by the concussion. But on the Asiatic side the bank had been completely carried away for a length of 120 feet and to a depth of 105 feet. As for the *Chatham* she had been reduced to a dishevelled twisted mass of ironwork; the removal of the debris was completed within a fortnight.

Devastating explosives, in alliance with the electric current, can be converted at times into a constructive tool of great execution. When the s.s. *Milwaukee*, of 7,300 tons burden, piled up on the rocks near Aberdeen on the morning of September 16th, 1898, the salvage engineer was persuaded to cut her in twain to recover the valuable after-part of the ship carrying the propelling machinery. When the White Star liner *Suevic* fouled the granite teeth encircling the Lizard, a similar marine amputation was performed. In each instance the tough plates forming the hull were severed by gelignite cartridges. The weight of the charge varied according to the nature of the work to be done. The largest single charge fired in the case of the White Star liner was 10 lb., while a charge of 8 lb. was necessary to cut through the keel.

For such marine surgery the charges have to be specially prepared. The cartridges are placed end to end in a roll of sail canvas, specially treated with india-rubber solution to secure waterproofness.



NOBEL DYNAMO EXPLODER
The electric impulse is generated by pushing the handle down smartly.

In this way, what may be described as a rope of explosives, is prepared. This is laid in sections along the line of severance. The placing of this strange surgeon's knife in the correct position is somewhat baffling at times. As a rule sand-bags, clusters of chains, and other extemporized weighted devices suffice to keep the tool in position. In the case of the *Milwaukee* 1,700 lb. of gelignite were consumed in 50 to 60 electric discharges. The *Suevic* was a larger vessel, and occupied a more exposed position, but the amputation of the bow was completed in six days; the average length of a cut performed by the cartridges was 2 inches.

WHEN THE ELECTRIC IMPULSE WAS SENT HOME

The water-tower at Port Talbot—in which and the adjoining wall 48 shot-holes were placed—heeling over after the charges had been fired.

Farming by explosives has now become an established practice, and one capable of extensive development. It offers the quickest method for removing tree stumps, digging ditches, planting trees, and even for breaking up the land preparatory to cultivation. Stumping is extremely simple. The root of the tree is first examined with a probing tool. Then a hole is drilled in a downward oblique direction, so as to bring the charge about centrally in relation to the heart of the stump. The charge is tamped home and fired from a short distance away. In bursting, the explosive lifts the stump and loosens the earth round the roots, thus permitting the latter to be easily withdrawn. If desired, the charge can be made sufficiently disruptive to split the stump longitudinally, and to tear it free from its roots. If heavy

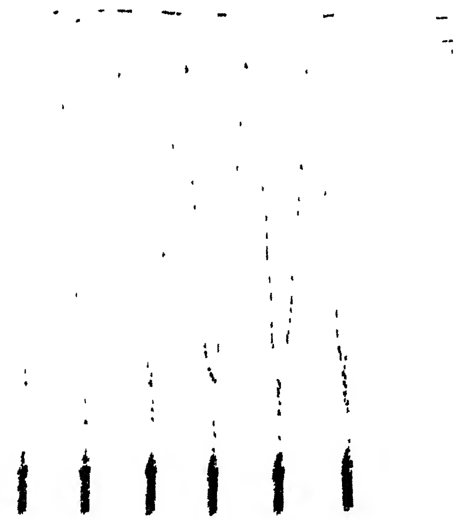
clearing work has to be done, several stumps may be connected up in series, and the ground thus ridded of this obstruction over an appreciable area in one stroke. It is not even necessary to fell the tree in the first instance; it can be brought down intact. The charge is inserted in the base of the tree as above described and fired. The explosion is of a relatively gentle character, but sufficient to induce the tree to topple over, generally with the wind, and in so doing it will tear up its main roots to be sawn off at leisure. Obviously, in such a case there must be ample space for the tree to fall in.

BRIDGE-WRECKING AT BRIDLINGTON STATION BY LOW-TENSION ELECTRICITY

Top of the bridge arches showing coupling up of the charges by Cordeau detonant. The rows were connected in series. The Cordeau lines are plainly visible. Ships' chains were laid over the shot-holes to prevent flying debris.

Irrigation ditches are driven by drilling the holes at an angle to the line of the trench. In this instance a long length of charges may be connected up in series for simultaneous firing. When the work is properly executed the ditch will be truly driven to the desired depth and with banks of the correct slope. No subsequent work is involved because the earth is blown out of the line of trench and distributed over the land on either side. The drilling of the holes, tamping the shots and connecting-up for electric detonation, do not necessarily involve the services of an expert, nor is the task attended with any pronounced danger owing to the ingenuity which has been, and still is being, expended in the fabrication of safe explosives.

The possible uses of explosives in combination with electrical detonation upon the land are too numerous and diversified



SERIES CONNEXION OF ELECTRIC DETONATORS FOR GROUP FIRING.

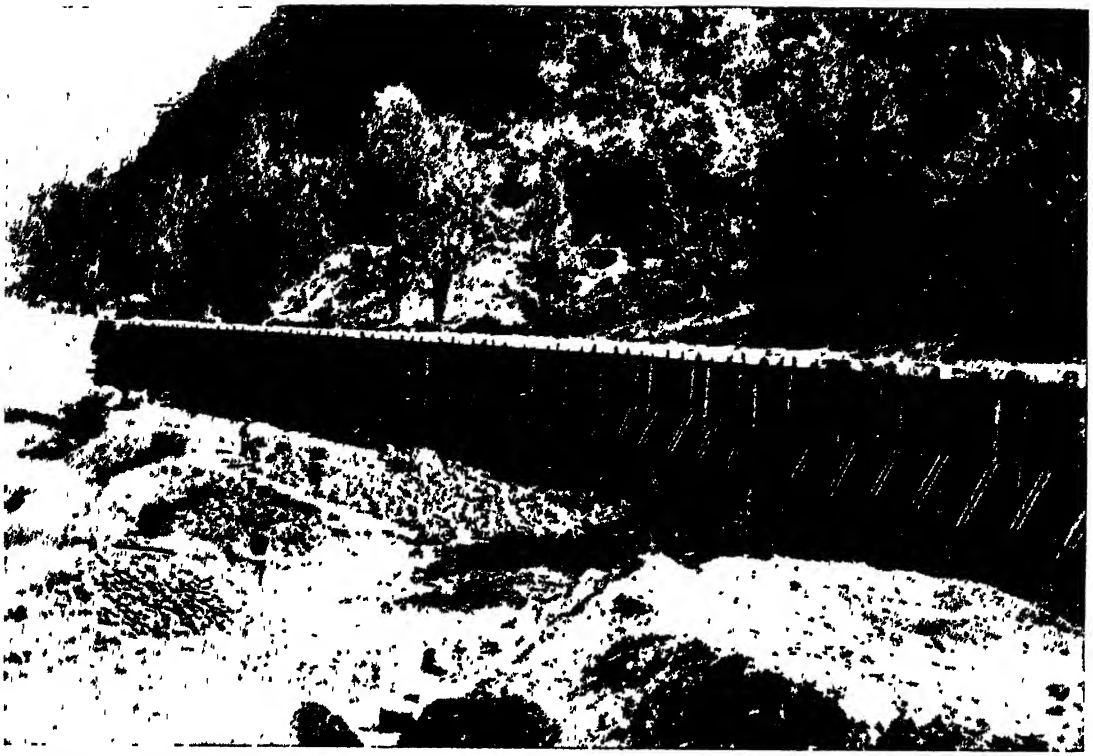
The two end wires are connected to the cable leading to exploder.

to relate in detail, but they can be utilized either in conjunction with, or instead of, conventional tillage methods. There are many farms of high productivity, scattered throughout the world, which are never touched with the conventional plough. Explosives are employed exclusively for breaking up the soil, and, owing to the manner in which the earth is shattered and the subsoil disintegrated, crops may be planted without any additional preparation. Fence posts are sunk in holes driven by explosives, and orchards are planted by the self-same agency. Experience has proved that the preparation of the necessary hole to receive a young tree by this means is preferable to the procedure generally favoured. The subsoil is so broken up as to enable the tender roots to secure a firm and healthy grip, and by securing adequate nourishment, to develop rapidly.

Another application of the electrically fired explosive charge may be mentioned. This is "well torpedoing," to increase the flow of water from an artesian well. The explosive is secured in a substantial envelope of leather, stout rubber, tin or even iron or steel. Before the outer casing is sealed to obtain watertightness the detonator, with the electric fuse-wires coupled thereto, is introduced and secured. The electric wires are then joined to the cable, and the charge is lowered into the well by means of an independent line to support the weight. If the bore-hole should be deep, and the pressure of water considerable, it is necessary to use a specially insulated cable. The charge is lowered with extreme care to ensure it arriving at the desired point in such a condition as to render its subsequent explosion positive. Firing is either performed by a rack-bar or by a twist exploder. The detonation may widen the existing cracks and fissures through which the water is flowing, or form new vents in the water-bearing stratum. In some instances the wall of the well is shattered, thus allowing the water which has been held back to enter the bore-hole.

TESTING A LOW-TENSION ELECTRIC DETONATOR

For safety the detonator is placed in the iron pot shown on the left, and the two wires are led to the terminals of the galvanometer. If the needle moves, the detonator is sound.



By courtesy of "The World's Work"

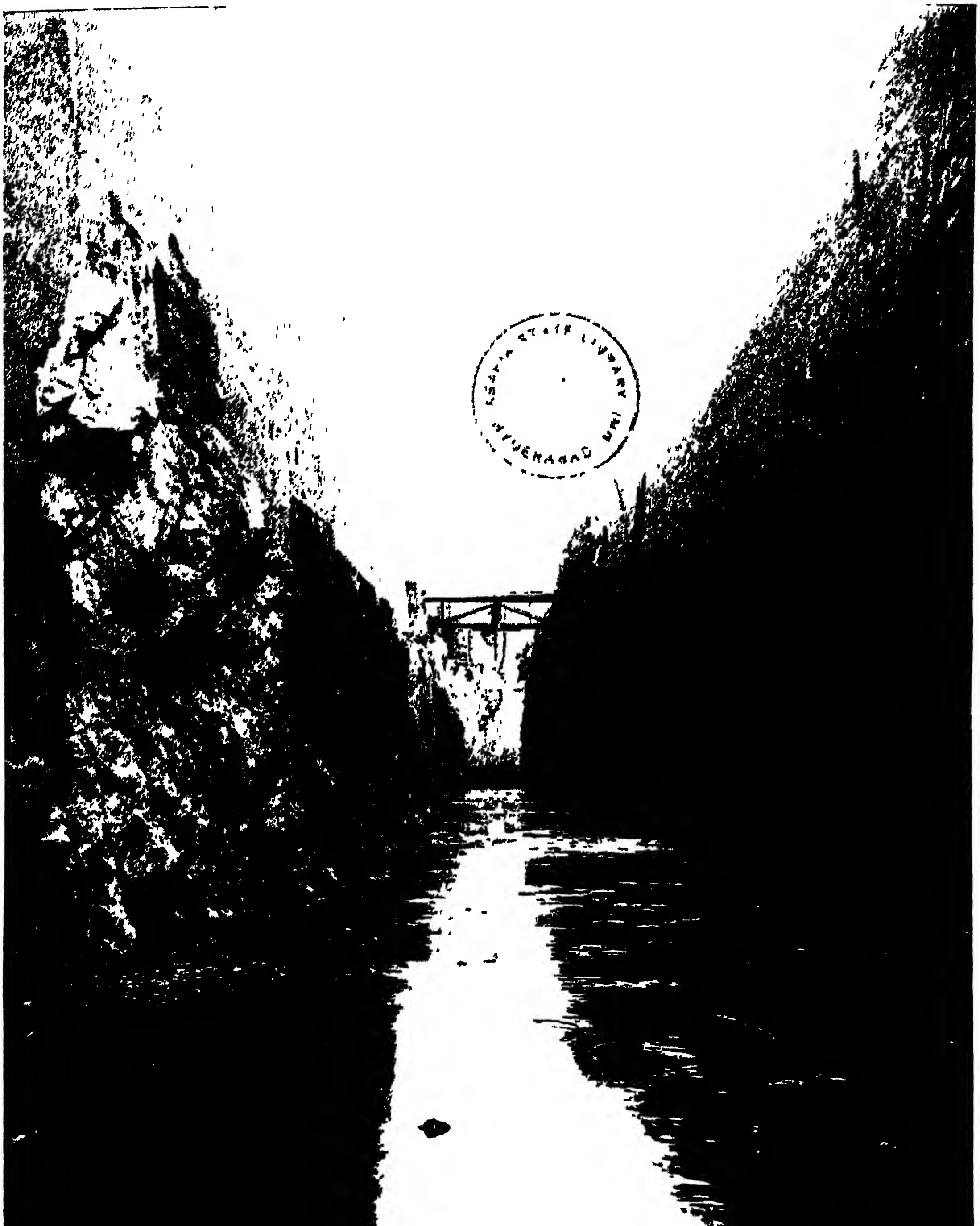
TIMBER FLUME CARRYING THE WATER DRAWN FROM THE JHELUM RIVER TO DRIVE THE TURBINES IN KASHMIR'S NOTABLE HYDRO-ELECTRIC PLANT.

The timber flume is a type of conduit which the engineer uses to carry his water to the power-house. It is really a huge box-like ditch built of heavy baulks.

Wonders of Pipe-line Construction—I

HOW THE ENGINEER HAS SOLVED THE PROBLEM OF CONDUCTING WATER FROM HIS STORAGE RESERVOIRS TO THE DISTANT POWER-STATION

IN the plotting of his hydro-electric system the engineer strives to secure as high a static head, or pressure of water, as he can, and to turn the whole of that fall to full advantage. To fulfil this requirement it is often necessary to place the power-station containing the generating units some distance from, and below the lake which has been formed for the storage of the water. In such circumstances ways and means must be devised for the conduct of the source of energy to the power-station, and in such a manner as to have it under complete control. Water is a somewhat mysterious force to the lay mind; but little conception prevails concerning its potential energy. A cubic foot of water per second, falling 1,000 feet, will develop 11 horse-power. There are many plants in operation to-day where many hundreds of cubic feet of water per second are being hurled or conducted from heights running up to 4,000 feet. Obviously, therefore, elaborate measures must be observed to keep this tremendous water-power in leash so that the exact requirements of



By courtesy of E. A. Vormals Schuckert & Co., Christiania

MODERN HYDRO-ELECTRICS SOMETIMES INVOLVE THE CONSTRUCTION OF IMPOSING CHANNELS TO LEAD THE WATER TO THE POWER-HOUSE.

The canal blasted through the solid rock and lined with concrete to conduct the water to the turbines of the Glommen hydraulic-power plant in Norway.

the electro-mechanical engineers may be satisfactorily fulfilled.

The method whereby the water is led from the reservoir in which it is stored or collected, to the chamber or forebay serving the plant installed in the power-house, varies according to the local conditions. There is the natural waterway, as represented by the river, of course, to hand, but the engineer prefers to be independent of Nature in this connexion, although the waterway itself is introduced into the general scheme and is allotted specific functions. The independent artery contrived for the exclusive movement of the water which is to be turned to power-producing account, may take the form of an open concrete canal or ditch hewn out of the solid rock, a tunnel, a huge iron or wooden pipe, or a large wooden trough technically known as a flume. But, whatever the nature of the conduit adopted, it is generally described as a "pipe-line," and it is by no means uncommon for a single installation to embrace distinctive sections representative of every method of conducting the water from the reservoir to the power-house. Nevertheless, in every instance, the outstanding feature of such works is their imposing dimensions. Many water-power canals are wider and deeper than the channels specially built for the maintenance of navigation; indeed they might be employed for such a purpose but for the fact that the demand for power is more vital.

The Tunnel and Hydro-electrics

When we pause to reflect upon the daring and ingenuity of the engineer in connexion with the boring of tunnels, we naturally turn our thoughts to such undertakings as have been driven through formidable mountain barriers and under wide rivers for the movement of railway trains. The tunnel is popularly associated with the steel road; but to-day it is every whit as indispensable to the movement of water for the generation of electricity. The work which has been accomplished in this field, and for this little known interest, is quite as remarkable as that identified with the railway; in many instances such works have proved to be quite as perplexing and as exciting to drive, while in point of magnitude they are also arresting.

Norwegian Enterprises

When it was decided to embark upon the manufacture of atmospheric nitrates in Norway, the enormous volume of electric energy required compelled the fulfilment of a comprehensive hydro-electric scheme. Lake Mjosvand, sprawling over 25 square miles among the Telemarken Hills at an elevation of 3,000 feet, was regarded as an excellent reservoir. The level of the lake was raised 39 feet by the erection of a dam at the natural outlet. The water for the generating station is drawn off at a convenient point, and for four miles is led through an open channel. Then it is turned into a tunnel, 2½ miles in length, to be brought to the power-station at the head of the Rjukan Fall, where the natural outlet from the lake takes a spectacular plunge of 320 feet into the canyon below. But the water, after passing through the turbines, is not permitted to join the river and hurl itself over the cliff. Instead, it is led from the tail-race into a second tunnel, 3 miles in length, and carried through a second downward journey of 830 feet to another power-house, where it is again compelled to dissipate the energy it has gathered during its second descent. After emerging from these lower water-wheels the water is released to flow into the fiord. In this instance, it will be observed, the self-same water is compelled to do duty twice in the course of its controlled descent.

Another Norwegian hydro-electric undertaking, known as the Tysse plant, which is also identified with the production of synthetic nitrates, draws its supply of water from Lake Ringedal, lying

in a hollow among the mountains at an elevation of 1,430 feet. The level of this sheet of water was likewise raised to give a total storage capacity of 12,360,000,000 cubic feet. The water brought under subserviency is drawn off from the lake and conducted underground for a distance of 11,430 feet, to be brought to the top of the cliff dropping abruptly into the fiord, and above the power-house, 1,260 feet below. The last lap of the water's journey is covered in a pipe-line, one of the steepest in the world.

Vancouver's Water-power

When the Vancouver Power Company, a subsidiary of the undertaking financed by British-Canadian capital, and known as the British Columbia Electric Railway Company, Limited, cast around for a cheap means of generating electricity, to meet the thousand and one power needs of the City of Vancouver and its environs, it decided to press Lake Coquitlam into this duty. Accordingly, a low dam was thrown across the outlet of the lake to increase its storage capacity to 1,096,000,000 cubic feet. But, in the course of a few years, owing to the phenomenal growth of the Pacific port and the expansion of its varied industries, this supply became inadequate, and the engineers were compelled to meet the requirements for the future. Again they turned to Lake Coquitlam, because it was possible to increase its storage capacity. Under the original scheme a certain volume of water, exceeding the power requirements, was permitted to escape and thus run to waste. It was decided to turn this lost water to useful account by lifting the level of the lake, and to divert the stored water into an adjacent reservoir, Lake Buntzen.

It appeared to be an easy straightforward project, but the engineers were fully cognizant of the fact that the realization of the scheme was going to be associated with some baffling problems. The lake, while wildly picturesque, is in as rugged a situation as could be conceived. The water fills a depression among the mountains at an altitude of 432 feet, and is fed with water overflowing from Lake Disappointment, 2,568 feet nearer the clouds and some 13 miles farther inland; the connecting link is the tumultuous Coquitlam River. Owing to the purity of the water born upon the mountain slopes, Lake Coquitlam serves as the source of the water-supply to New Westminster. By raising the level of the lake and increasing the storage capacity to 7,873,000,000 cubic feet over and above the water-supply requirements, the New Westminster waterworks would be rendered absolutely useless. The engineers thus were confronted with the necessity to secure the necessary power for the generation of additional electricity, and to provide the neighbouring town with new facilities for satisfying its domestic water needs.

A Colossal Tunnel

The level of the lake was raised by building a dam, 1,200 feet in length, including the spillway, and 99 feet in height in the centre. The building of the dam, which is of the hydraulic-filled type, that is to say, of debris washed down by powerful water jets, or monitors, and led through flumes to be deposited upon the site, was an imposing task in itself, but it was excelled by the amount of tunnelling work which had to be carried out. During the construction of the barrage the outflow from the lake had to be kept under control, and this was accomplished by leading it by way of a tunnel driven through the ledge of solid rock forming the spillway. This tunnel is 490 feet in length, and 26 feet in width by 18½ feet in height to the crown of the arched roof, so that it exceeds in its sectional area the huge double-track tunnels which have been built for the movement of trains through formidable obstructions. For a distance of 190 feet this tunnel is completely lined with concrete;

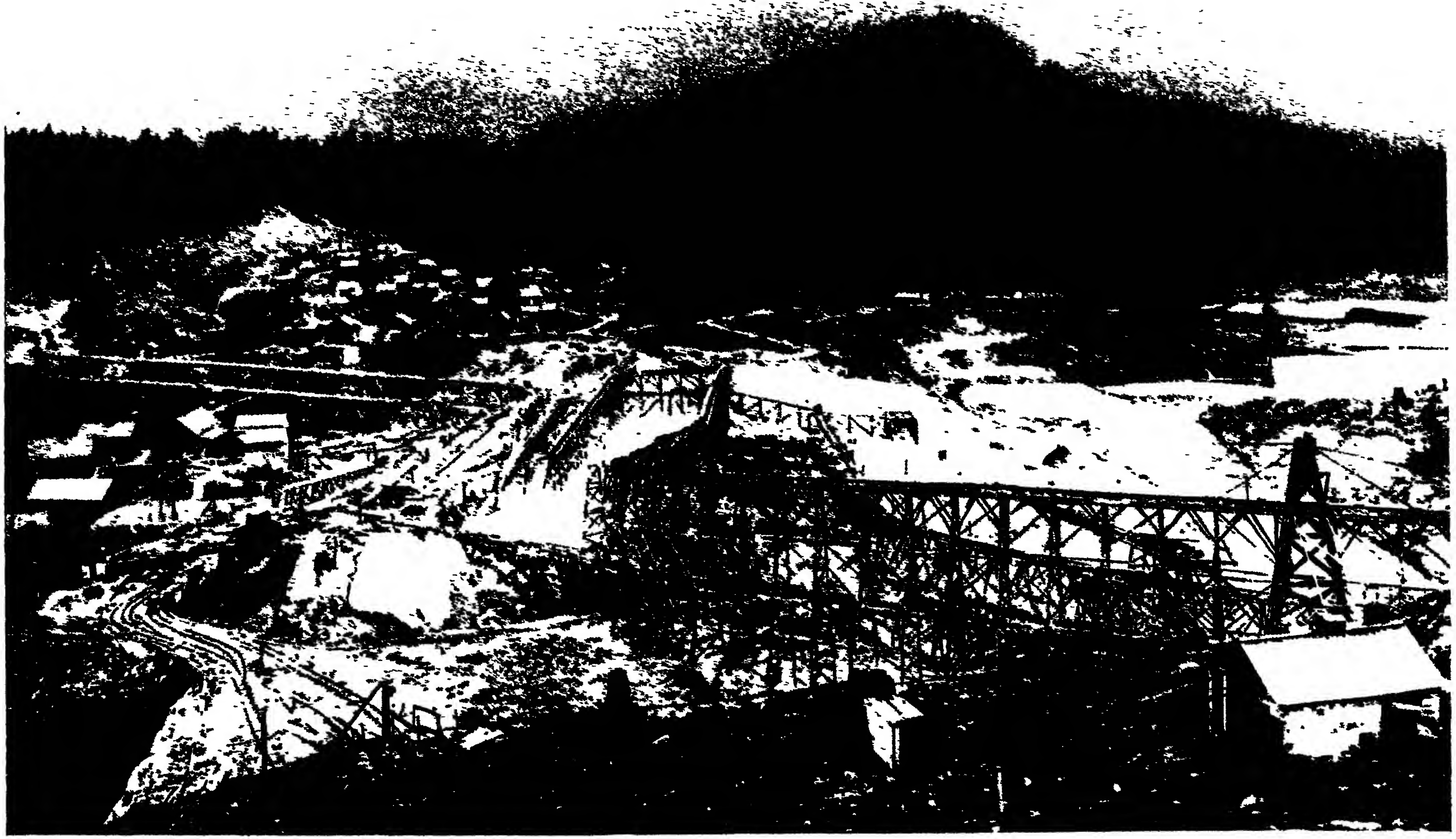
the remaining section of its length is lined only on the floor and sides.

The foregoing impressive dimensions were necessary to take care of the flow of 12,000 cubic feet per second of water, representing a discharge equal to the highest flood ever recorded; but in point of fact, the tunnel, during the whole of the constructional work, was not called upon to handle more than 6,500 cubic feet per second. The tunnel is approached through a cutting 850 feet in length, while the water, after leaving the bore, is carried through another channel hewn out of the solid rock, to be emptied into the river lower down. The necessity to provide New Westminster with new headworks for its water-supply involved the construction of a new intake tower and the driving of a tunnel 1,938 feet in length, 4 feet in width by 6½ feet in height, passing under the huge sluice tunnel mentioned above. The water carried through this lower tunnel is delivered into a distributing chamber whence extend the mains to the neighbouring town.

THE ORIGINAL COQUITLAM DAM, NEW WESTMINSTER.
Showing intake and screen house on the right. This dam was built to secure water-power to generate electricity for the City of Vancouver.

The work described, despite its heavy character, merely represented the preliminaries to the principal scheme. The two lakes, Coquitlam and Buntzen, are separated by a formidable barrier, a massive hump of granite, rising to a height of 4,000 feet. When the first hydro-electric development scheme was taken in hand, this dividing wall was pierced by a tunnel 9 feet square, 12,650 feet in length, to give a flow of 500 cubic feet of water per second. It was driven through the solid rock from the opposite ends. Despite the restriction of attack to the two ends, the difficult conditions experienced, the severity of the winter, the relatively cramped space at the working-faces, and the stern resistance put up by the rock, the tunnel, commenced in 1902, was completed in 1903. As the bore extends through dense granite from end to end, the necessity to line it did not arise.

When this tunnel was driven the engineers computed that it would be able to carry sufficient water to meet all the power



THE STORAGE RESERVOIR, OF 7,873,000,000 CUBIC FEET CAPACITY, FOR THE SUPPLY OF VANCOUVER WITH ELECTRICITY.

The trestling-supported flumes through which 544,710 cubic yards of material were sluiced with 215,000,000 cubic feet of water by monitors to form the New Coquitlam Dam.

demands likely to arise for many years to come, but the phenomenal growth of Vancouver shattered all these conclusions. Accordingly, when the new enlarging works at Lake Coquitlam were undertaken, one of roof and the upper parts of the sides to give the desired cross-area, so that in section the tunnel resembles an egg stood on its pointed end. The adoption of the overhead method of excavation involved

HOW THE HYDRO-ELECTRICAL ENGINEER FITS HIS POWER-HOUSES INTO TIGHT CORNERS.
To increase the output of energy from Lake Coquitlam by 40,500 horse-power, the engineer found it impossible to extend the existing station upon Lake Buntzen—shown on the extreme left—and so had to build a second power-house—shown on the right—about a third of a mile distant. The water is led to the second building through a tunnel 1,800 feet in length, piercing the intervening barrier of rock.

the most important phases of the task was to increase the flow of water from Lake Coquitlam into Lake Buntzen. It was suggested that a second tunnel should be driven through the mountain, but further consideration of the scheme led to the conclusion that the most satisfactory solution would be to enlarge the existing tunnel from the sectional area of 81 to 192 square feet.

This end was to be achieved, not by widening out the tunnel on all sides, but by the removal of sufficient rock from the the erection of a simple yet somewhat elaborate timber staging at the working-face, the cross-members, spaced about 6 feet apart, being wedged across the tunnel. This staging carried a wooden floor. A railway track was laid through the tunnel to enable the trucks to be brought under the staging, into which the spoil, brought down by the explosives and deposited upon the wooden staging, was shot direct. The enlarging work was conducted from several points simultaneously, but it was discovered that the greater the

number of working-faces the more obstinate the obstruction offered in the tunnel, for the simple reason that the elaborate timbering had to be erected at every working-point.

THE PIPE-LINE CLIMB OF THE MOUNTAIN HUMP.

Building the three penstocks, 8½ feet in diameter, connecting the turbines in the second power-house upon Lake Buntzen with the pressure tunnel carried through the mountain. The ascent is so steep as to be almost vertical.

About 450 men were engaged upon the task and they were divided into two 10-hour shifts. The day-shift did nothing but the drilling. Upon retiring from the scene the shots which had been tamped home were fired, bringing down hundreds of tons of rock. The night-shift's operations were confined to the removal of all the spoil, so that when the drillers resumed the next morning they could settle down to their attack upon the rock without delay. The night-shift was taken into the tunnel by electric trains as far as the first heap of debris brought down by the blast. This was cleared, and the train then pushed on to the next blast with its mass of spoil, and so on until each pile had been cleared. As soon as the trains were loaded they were hauled out of the bore, the electric engine uncoupled and a lighter locomotive attached to the train to haul it to the dumping-point. While only a single track was laid through the tunnel, sidings were provided at intervals to permit trains to pass one another. The spoil was shot into Lake Buntzen, there being a great depth of water by the tunnel portal, so that dumping was relatively an inexpensive operation.

The widening of the tunnel suffered severe and repeated delays, inasmuch as work had to be frequently suspended to allow water to be carried through from Lake Coquitlam to charge Lake Buntzen. The adjustment of work to water was difficult to fulfil. In 1908, when work was started, progress fell behind expectations for this very reason. During the summer the run-off from the watershed of Lake Buntzen was so light that tunnel widening had to be interrupted more freely than ever had been anticipated, because naturally, when water was wanted

the tunnel-borers had to retire from the scene. By July, 1910, the tunnel had been widened to the required dimensions for a distance of 1,800 feet from the portal at Lake Buntzen—the work could only be conducted from this end—and drilling completed to the 3,000-feet post.

A crisis developed. The enlarging work must be accelerated because the demand for power was rising at such a rapid rate as to place the company in a quandary. Sufficient energy was not forthcoming from the hydro-electric station in operation. In fact, to meet the situation, the company had had to rush through a special auxiliary steam-plant in the city which already was working up to its utmost capacity.

How could tunnel widening be speeded up? That was the crucial question. The situation was discussed, and it was decided by the engineers to modify the system which had been adopted. Instead of widening out the tunnel on both sides and the roof, why not confine the work to the roof and one side to give the desired 192 square feet of section? The suggestion was adopted, and although it entailed the revision of the working arrangements, it proved conspicuously successful. Widening went ahead with enhanced speed while, at the same time, it permitted the introduction of a simpler means of switching the tunnel in or out of water-carrying duty as desired.

Widening the Tunnel

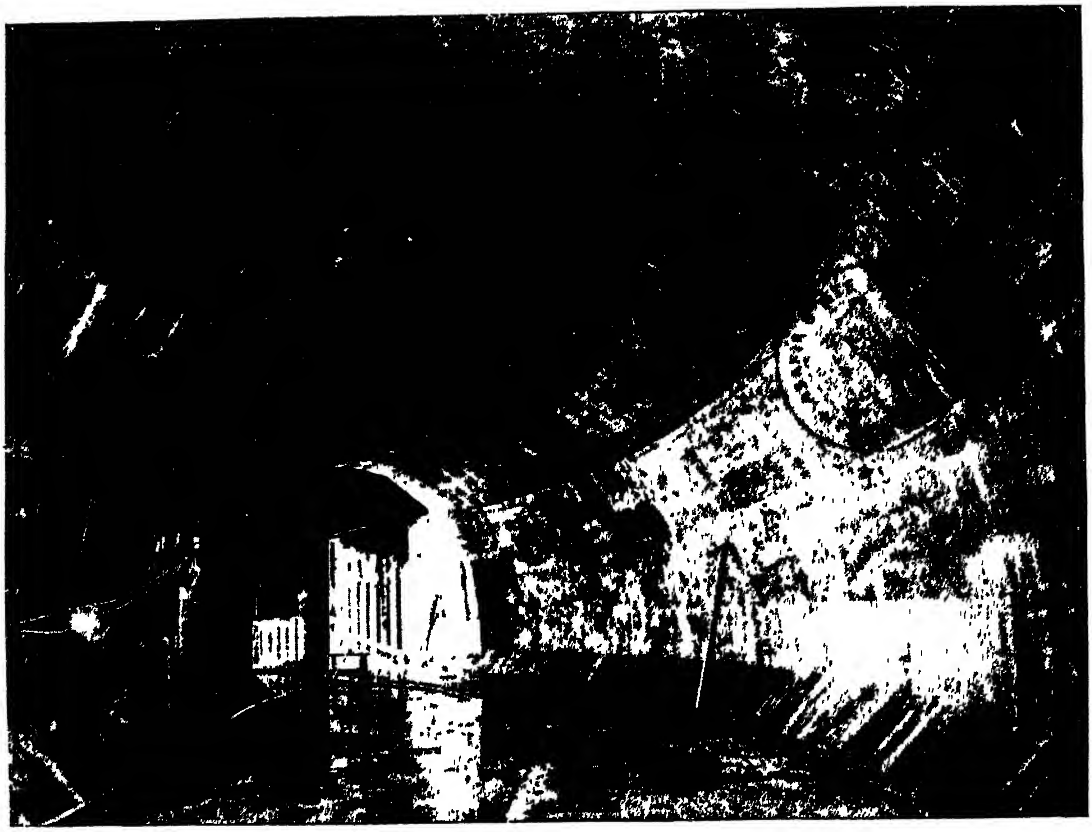
Work continued uninterruptedly until the water-level of Lake Buntzen fell to a certain point. When this was reached tunnel widening was suspended to permit the flow of water until the lake had been refilled. Furthermore, the period of waiting for the tunnel to empty after the water had been shut off at the Coquitlam end was reduced. An automatic shutter-dam was placed at a certain point in the tunnel in advance of the borers. This was pivoted on its horizontal axis and closed automatically when the water in the tunnel reached a depth of 4 feet. Consequently, when the Coquitlam gate was closed and the water in the tunnel fell to the 4-foot level the automatic dam closed, holding back all the water standing in the tunnel from that point to the Coquitlam portal. This reduced the emptying length to that section lying between the automatic dam and the Buntzen portal.

As the Coquitlam end was approached another peculiar difficulty arose. The original tunnel was not driven on a continuously falling grade from one end to the other, but in such a manner that, when the water was shut off and the tunnel emptied, there was a depression of about 5,000 feet in length, in which the water collected to a depth of 4 feet. Since this prevented the borers from completing their work, it had to be overcome. The first suggestion was to fill the sump with the spoil brought down in the widening operation, but this proposal was abandoned in favour of pumping. A small water-tight compartment was formed in one wall of the tunnel near the sump and therein an electrically-driven motor-pump was installed. When the Coquitlam gate was closed and the tunnel was draining, this pump was set going, and the sump was promptly emptied into Lake Coquitlam.

Adjusting the Work to Water Conditions

The expulsion of the noxious gases from the bore, after shooting had been completed, was also carried out expeditiously. A large electrically-driven motor-exhaust fan was set up at the Buntzen end, and, as this had a capacity of 56,000 cubic feet of air per minute, the tunnel could be cleared of all noxious gases within half an hour, the fresh air flowing in at the Coquitlam end. All the plant was electrically operated, a temporary 2,200-volt line being brought to the works for light and power. The enlargement of the tunnel, commenced in 1908, was completed in

March, 1911, but during the whole of this period the drillers and excavators were only able to put in 100 actual working days, owing to the frequent interruptions for water-service. The average speed of advance was 100 feet of enlargement to full dimensions per day of two shifts. By widening the tunnel in this manner the flow of water was increased to about 1,350 cubic feet per second, which it is estimated will satisfy requirements for many years to come.



LOOKING THROUGH THE COQUITLAM DAM SLUICE TUNNEL TOWARDS HEAD GATES
This bore, which is 490 feet long, 26 feet wide by 18½ feet high, was built to carry a possible flow of 12,000 cubic feet of water per second.

Lake Buntzen is a small sheet of water, and its storage capacity under natural conditions severely limited, because it drains only a small area; but it constitutes an admirable forebay for the power-plants. Its storage capacity was increased to 6,000 acre-feet by the erection of a dam 361 feet in height at its south end. When it became necessary to increase the output of the generating installation it was found impossible to enlarge the existing power-house; while, owing to the cliffs rising sheer from the water of the north arm of Burrard Inlet, there was only one other site, a small shelf or bench, upon which the second power-house could be erected, and this was some distance from the original building. To conduct the water to this second station involved the driving of another tunnel for 1,800 feet through an intervening hump. This tunnel, of the pressure type, has an internal diameter of 14 feet 8 inches, and, owing to the character of the soil, had to be lined with concrete from end to end. Its construction was conducted from six points simultaneously, the relatively shallow depth of the hill permitting the sinking of two intermediate

LEADING THE WATER DOWN THE MOUNTAIN-SIDE BY TIMBER FLUME.

This form of conduit is freely favoured upon the Pacific slope of Canada and the United States of America. It winds sinuously down the ravine to maintain the gradual fall and the desired velocity of the water. The above picture gives a glimpse of the 5½ miles of wooden ditch forming part of the Jordan River Development upon Vancouver Island. A few feet above may be seen the railway winding up the canyon approximately parallel with the water channel.

shafts to the tunnel level. This tunnel, owing to its character and duty, may also be described as a large pipe-line, but hewn out of the rock and finished in concrete.

The Flume

The flume is a much-favoured method of conducting water to the power-house when the conditions are propitious to the adoption of the principle. The flume may be compared with a big trough of square section, but in some instances the floor is given a concave form. Both systems are practised, but it is the former which has the most extensive vogue, as it is easier and cheaper to build and to maintain. In both instances the flume is open at the top, so might be aptly described as a wooden ditch. Generally speaking, it is not to be commended in districts exposed to intense solar heat, for the simple reason that the sun playing upon the external surface of the wood causes it to contract, split, and warp, rendering it difficult to preserve water-tightness. In one case, where a flume was kept empty for four or five days, the sun played such havoc as to open up all the longitudinal seams in the bottom in which the fine sand collected, rendering it impossible to re-tighten the structure; the loss of water, through leakage, when the supply was resumed, attained to about 15 per cent.

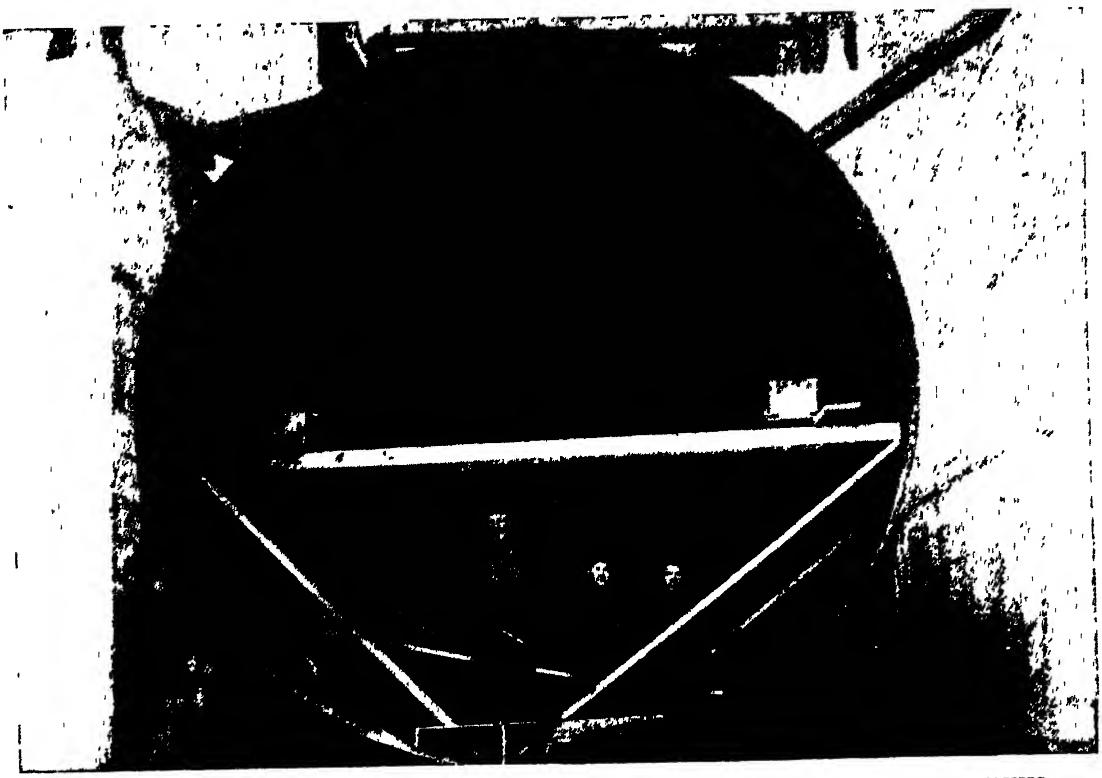
The flume is a conspicuous feature of many of the hydro-electric installations which have been completed in the western districts of the United States and Canada. Some of these undertakings are of impressive magnitude and are certainly remarkable achievements, following as they do the contour of the rugged, broken mountain side, and gradually falling in accordance with the engineer's calculations. One of the most notable undertakings of this character is to be found upon the Electron section of the Puget Sound Power and Light Company. The western slopes of Mount Rainier sustain five large glaciers, which give birth to numerous rivulets that finally commingle to form the Puyallup River. This waterway follows a troubled course, having eroded a narrow, twisting and broken channel through the cliffs, and tumbling 1,000 feet before emerging from the canyon to flow more placidly through the lowlands.

By building a crib dam high up among the mountains, the engineers diverted the water through a masonry intake into one of these large timber ditches. It measures 8 feet square and has been laid along the mountain side, paralleling approximately the tortuous course of the waterway in the depths of the canyon below. It is a massive structure, supported upon heavy timber trestling. The open top face, with its wooden cross-pieces, forms the bed for the metals of a light railway, while a wide plank laid between the metals serves as a causeway for the maintenance gangs. For ten miles this flume winds down the mountain-side, at places clinging limpet-like to the face of steep precipices, and finally discharges into a large reservoir and settling basin on the brow of a precipice overlooking the power-house by the riverside 872 feet below.

The Jordan River Flume

Another interesting flume which has been built to provide hydro-electric power service is that forming part of the Jordan River Development of the Vancouver Island Power Company, controlled by the combination identified with the Coquitlam-Buntzen enterprise. The Jordan River is a typical mountain stream, emptying into the Straits of San Juan de Fuca, about 36 miles west of the city of Victoria. At the point where this stream swings through a yawning rugged canyon, with lofty walls on either side, a concrete dam of the Ambursen type has been erected. It has a length of 891 feet along its crest, and is 126 feet in height in the centre, the surface of the water thus being lifted to 1,152 feet above the Pacific.

Practically the whole of this static head is turned to account, because the powerhouse is built upon the beach at the estuary of the river, and is thus virtually at sea-level. For the first $5\frac{1}{2}$ miles of its journey, after shrink and the seams open, the fine particles are liable to work into the space thus presented, defying all subsequent tendency to close up under the expansion exerted by the water saturating the wood, or the



A MAMMOTH PENSTOCK FOR A HIGH-POWER HYDRO-ELECTRIC PLANT IN THE MAKING.
These huge tunnels of steel, exceeding in diameter our underground railway tubes, carry the water over the last lap of its journey from the forebay to the turbines.

leaving the dam, the water flows through a timber flume, following the east bank in its amazing twists and turns, clinging precariously at places to slender foundations springing from the mountain flanks. This flume is built throughout of timber, measures 6 feet wide by 6 feet deep, and falls steadily and continuously at 1 in 1,000 feet, having been designed to give a flow of 175 cubic feet of water per second. This being in excess of contemporary requirements, the sides of the box have only been boarded up to a sufficient height to secure a flow of 75 cubic feet per second.

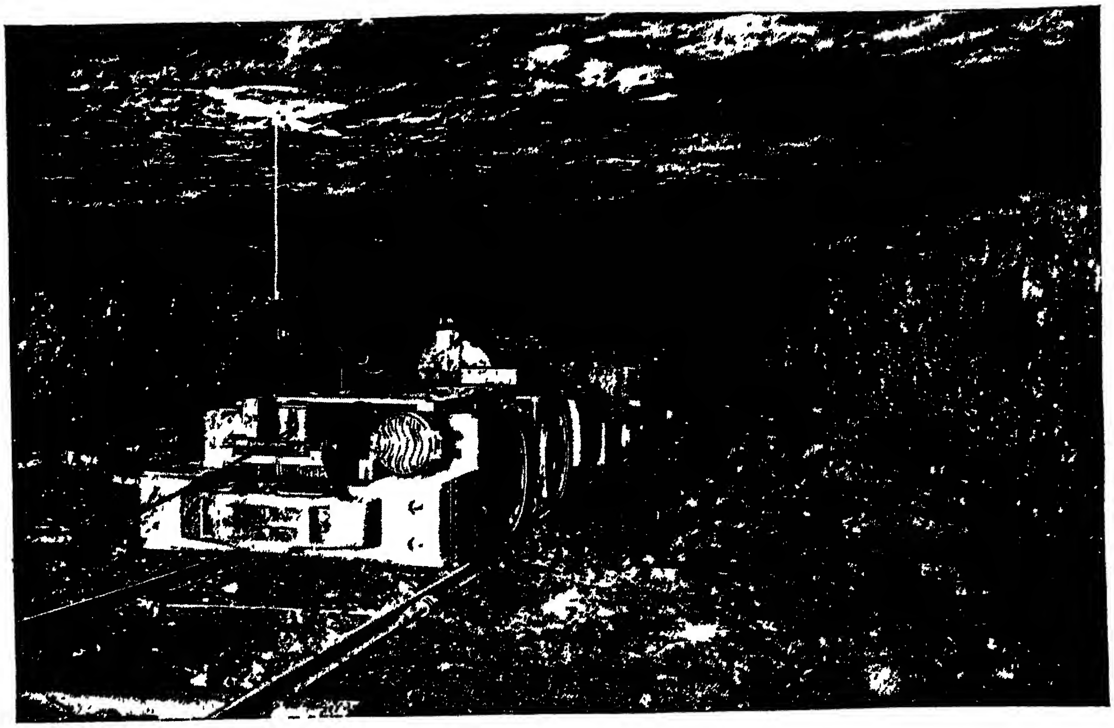
Sand and silt are the two relentless enemies of the flume. Should the staves tightening efforts of the maintenance gang. Leakage is thus likely to arise. As the water moves through the flume, the particles carried in suspension, being heavy, naturally sink to the bottom, forming a sediment, but one which is ever moving forward. Steps are taken to trap this foreign matter at intervals so that it may readily be removed periodically. In the case of the Jordan River flume, traps are installed at five intermediate points. The trap is a simple device, resembling a box, formed by dropping the floor of the flume about 3 feet below its normal level and fitted with a gate. Practically the whole of the silt thrown down and rolled forward along

the floor of the conduit falls sooner or later into one or other of these boxes. These traps are also of distinct value for the emergency emptying of the flume after the head-gate has been closed. The Jordan River flume empties into a lake, which has been created in a favourable depression to form a forebay, having a storage of 4,350,000 cubic feet, whence the water is drawn for conduct over its second and final stage to the turbines through riveted steel pipe-lines.

Vancouver Island also provides an illustration of the flume with a semicircular floor. This was built to carry the water from the storage reservoir formed on the Puntledge River to furnish electric energy for the Dunsmuir Collieries. There the timber flume forms part of a system, 3,400 feet in length, some of which is canal. The last-named occurs where solid rock, sand, gravel, and clay are traversed, the ditch being lined with concrete. This conduit has many exceedingly sharp curves owing to the broken nature of the country. The timber flume was introduced to form connecting links between the sections of canal, but the carrying capacity is uniform throughout. The flumes are built up of staves $5\frac{7}{16}$ inches wide by $2\frac{9}{16}$ inches thick, laid on steel suspension rods of $\frac{3}{4}$ inch diameter, and spaced 24 inches apart. The steel suspension rods are supported by side girders, laid on trestle bents set 16 feet apart, these being securely braced to assure the requisite stiffness, and carried upon concrete footings to give stability. The flume has a width of 7 feet and measures 12 feet in depth; each side member, formed of two massive fir baulks, measures 16 inches wide by 3 inches thick, being clamped together and resting securely on the 12 inches square cap of each trestle bent.

THE FIRST HYDRO ELECTRIC INSTALLATION UPON LAKE BUNTZEN.

The power-house is built by the water's edge Running over the brow of the hill behind are the eight pipe-lines, varying in diameter from 48 to 84 inches, to connect with the tunnel, 12,650 feet long, whereby Lake Coquitlam is tapped. The spent water is being discharged from the turbines into the lake.



DEPRIVING THE PIT PONY OF ITS JOB

A "Jeffrey" electric motor hauling cars out of a room at the working-face by cable. The latter is wound in upon the reel mounted upon the forepart of the haulier, which acts in a stationary capacity during the operation.

Banishing the Pony from the Mine

THE REMARKABLE DEVELOPMENT OF THE ELECTRIC MINING LOCOMOTIVE

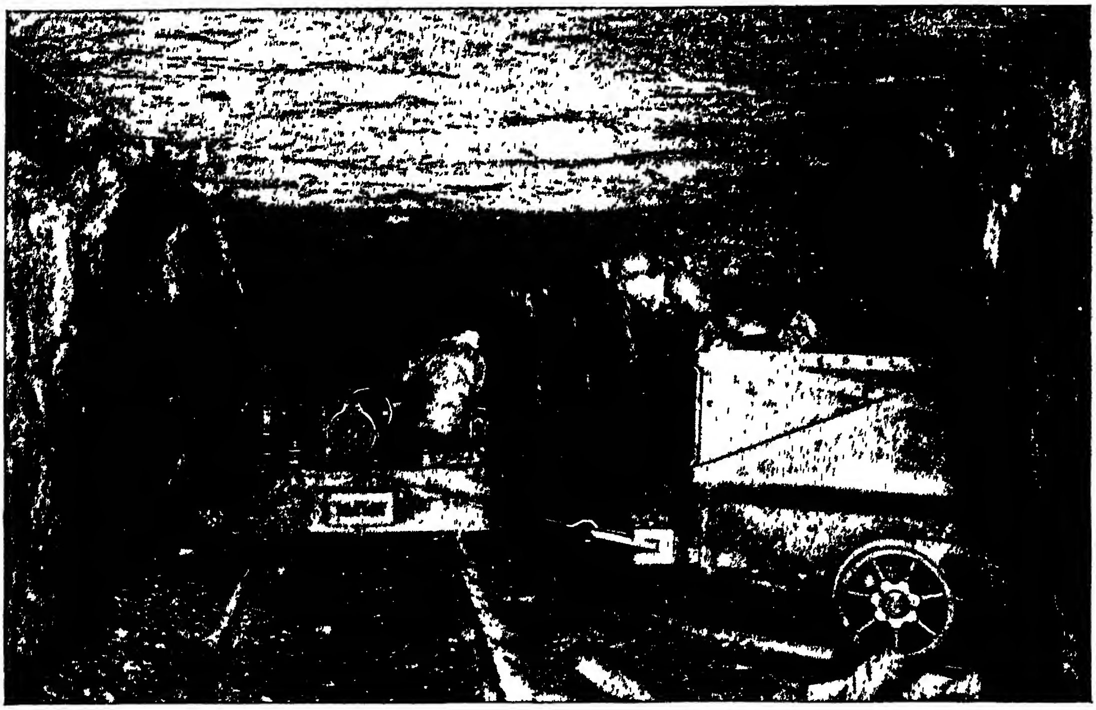
IF there be one field more than another in which mechanical effort should receive every possible encouragement, it is the mine. Public sympathy goes out to the animal, which, once taken underground to form part of the subterranean haulage machine, may only see the daylight and enjoy glimpses of the green pastures upon very rare occasions. But the need to condemn a pony to the Stygian darkness of a mine no longer prevails. Inventive effort has presented a more economical and powerful servant for such exacting duty, one which from its character is more peculiarly adapted to the majority of mines—the electric mule or mining locomotive.

A mine differs from every other display of human endeavour, and to a marked degree. The underground workings are tortuous in character, irregular in direction, severely undulating in regard to grade, rough and broken of surface, and generally of relatively small cross-section; while in many instances they twist and turn with marked abruptness, producing extremely sharp curves. And these burrowings constitute the sole avenues for the movement of all traffic to and from the working-faces. Under such conditions the

going is certain to be hard. The pony is efficient for haulage because it is sure-footed, while its intelligence enables the peculiarly difficult work to be fulfilled far more efficiently than might, perhaps, be supposed.

range of study with a view to evolving types for the distinctive requirements of the various mining activities.

The colliery proved to be the most attractive realm because of the vast possibilities which it presented for development,



THE ELECTRIC MULE AT WORK IN THE COAL-MINE.

An 8-ton Jeffrey electric locomotive pulling a loaded car out of a room with the crab attachment. Current is taken from the overhead conductor suspended from the roof through a trolley to the motor of the locomotive.

With accumulated knowledge concerning the industrial possibilities of the electric motor, thoughts were naturally turned towards the adaptation of this form of energy to mine traction. Some of the first efforts in this direction were conducted by the German electrical organization, Siemens and Halske, within a few years of the first public demonstration of the applicability of electric traction to the transport of passengers. In 1883 this firm supplied five small electric locomotives to the salt-mines at Neustassfurt, where they have given such excellent service as to be still in operation. The success of this initial effort prompted enthusiastic advocates of electric traction in other parts of the world to embrace this

and in this manifestation of inventive activity British and American thought were most pronounced. The last-named was probably presented with the most attractive outlook, inasmuch as geological and topographical conditions permit a high percentage of the American mines to be entered from a horizontal gallery, as opposed to the vertical shaft, which is the most extensively favoured, and indeed often the only practical means of gaining access to the seams of coal in Britain. By the adit tunnel it was rendered possible to lay down a network of railways to effect the direct transference of the coal, from the wall where it was brought down, to the surface screens and cleaning machinery,

which in some instances are situate some distance from the actual mine. On the other hand the British system necessitated the transference of the coal, hauled to the bottom of the shaft, to the cage, and its removal through the vertical plane to the surface.

Under the superior conditions presented by the American mines, it is not surprising that the electric locomotive has undergone the most rapid development in the United States. Once the haulage advantages of this mechanical mule were appreciated the movement underwent extensive expansion. Within a few years the design and construction of mining locomotives developed into a flourishing industry, especially by those firms which elected to make a speciality of this range of product, as for instance the Jeffrey Manufacturing Company, of Columbus, Ohio. Advance has been along standardized lines, producing locomotives of varying power capable of fulfilling the general all-round exigencies of mining service, no matter whether sought for haulage in coal or metal-ore workings.

American Mechanical Mules

This useful type of locomotive is impressively rugged and robust in construction. The frame is a massive rigidly bolted assembly. Service in the mine is particularly arduous; unless there be an ample margin of strength, breakdowns and withdrawals from service for overhaul, repairs and renewals are inevitable. The rough, uneven character of the road-bed sets up violent vibrations of a most destructive character. So to enable this constant pounding to be tolerated, it is essential that the electrical mule should be of heavy, substantial design.

The characteristic features of the frame are reproduced in the motors and other auxiliaries. The former are of large capacity and are fitted with ample ball-bearings. The incidental gears and pinions are likewise of liberal dimensions and heavy build. The three-point suspension, first advanced by Mr. Frank Sprague, the father of the modern tram-car, for such duty, is adopted on all locomotives of 10 tons and upwards, two points of the motor being on the axle, while the third is at the nose of the motor, which rocks on a suspension bar well-sprung above and below its point of support.

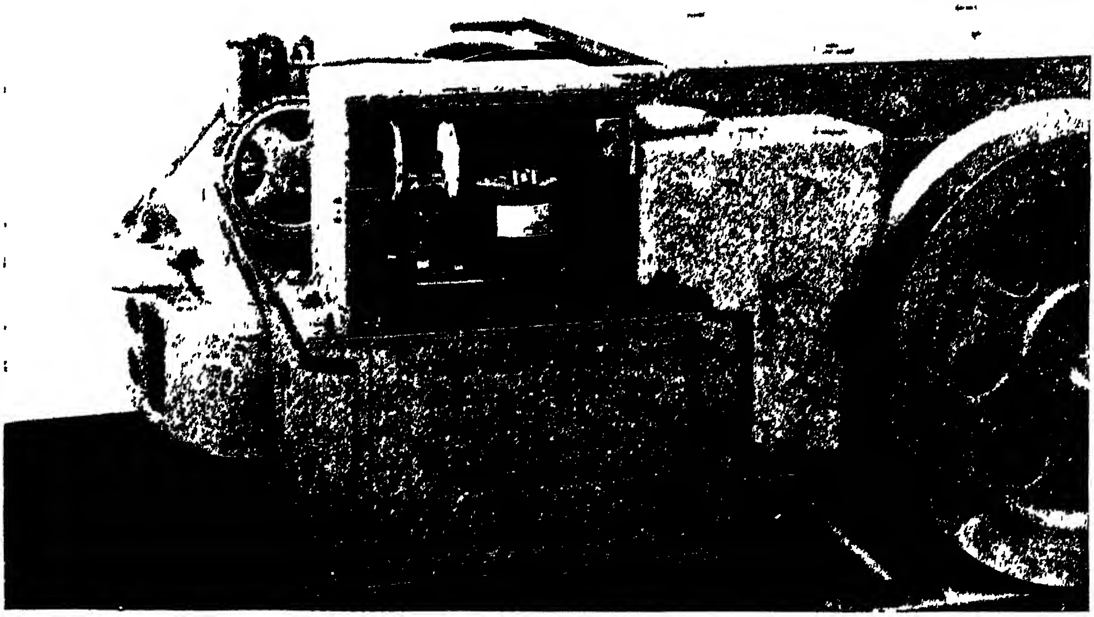
The electric mule of this type differs as markedly from the familiar conception of a locomotive as could be imagined. It might more appropriately be described as a shallow, heavy steel box mounted on wheels set close to the rails, because it is squat and low, though its very lines, especially in the large types, are indicative of strength. Externally there is little to suggest its function, the whole of the mechanism being enclosed. From the front it appears rather as if it were a massive battering-ram.

The motor-man is accommodated in a spacious well at the rear of the locomotive, deep down in the body of the tractor. The control is of the familiar drum-controller type with the addition of a useful accessory known as the "arc-master," and a solenoid switch. The former is mounted on top of the standard controller and takes the place of the usual handle of the controller, while the solenoid switch is mounted in a convenient position on the locomotive outside the controller casing. This feature has been introduced to take all the punishment from the contact-fingers, not only for the main break points but the intermediate points as well.

The Solenoid Switch

The arc-master controls the electric circuit of the operating coil in the solenoid switch. The movement of the arc-master handle to operate the controller for starting, first closes the solenoid switch, which, in turn, closes contact between the controller and the current collector trolley. The completion of the handle movement turns the controller on in the usual manner.

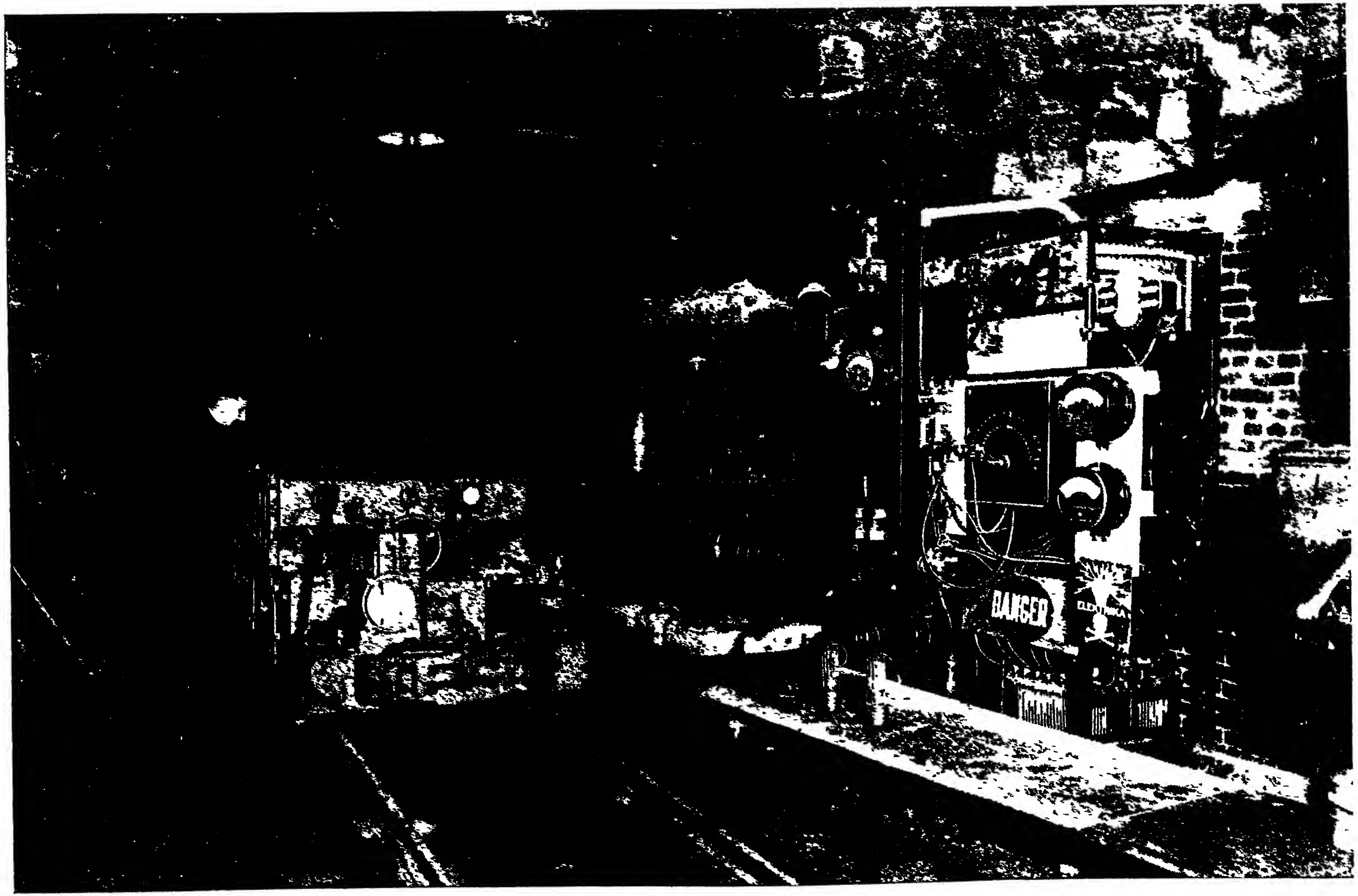
The movement of the handle in the reverse direction to throw the controller off, first opens the closing coil of the solenoid switch, causing the latter to open, thus breaking the circuit between the trolley and the controller. The further movement of the handle in the backward direction returns the controller cylinder to the off position without breaking any current. The solenoid switch is of very substantial design provided with large brush contact surface and heavy magnetic blow-out field.



THE CONTROL OF THE ELECTRIC MULE.
The solenoid switch, acting in conjunction with the arc-master, opened to show details of mechanism. By this device punishment of the fingers and contacts of the locomotive controller is avoided. It is mounted in a convenient place on the engine outside the controller-drum casing.

The weight and hauling capacity of the Jeffrey mine locomotive ranges from 4 to 30 tons, and the rated draw-bar pull from 20 to 25 per cent. of its weight, according as to whether it is fitted with iron or steel wheels, the coefficient of friction being 30 lb. per ton on level track, and 30 lb. per ton for each increase of 1 per cent. of grade. Thus the draw-bar pull of the 30-ton locomotive equipped with steel wheels is 15,000 lb. on the level with a haulage capacity of 500 tons. On a bank of 1 in 100 the draw-bar pull is 14,400 lb., and the haulage capacity 288 tons, while on a rise of 1 in 17 the draw-bar pull is 11,400 lb. and the haulage capacity 76 tons.

The method of operating the locomotive, that is, feeding it with the necessary current, varies according to the conditions prevailing in the mine, and in various parts of the underground workings. In the main galleries, unless the mine be fiery, a substantial permanent overhead trolley system may be installed with the conductor supported by adequate transverse or suspensory supports. As the mine is penetrated the definite well-ordered lay-out of the conductor may give place to an extemporized system of suspension, followed finally by the complete suppression of an overhead conductor. Or it may so happen that the mine is not adapted to the installation of



TAKING ON THE "JUICE."

A "Jeffrey" accumulator-driven mining locomotive being recharged at the underground station. If desired the exhausted battery can be removed intact from the locomotive by the overhead hoisting tackle and a full battery reinstated, permitting the locomotive to resume work at once. In many mines both battery- and trolley-driven electrics are used; the former are employed upon those sections where the provision of a conductor is difficult or unnecessary

an overhead system, owing to the clearance being too low or to some other factor. These varying conditions have to be met, and are fulfilled by adapting the locomotive either for trolley service, collecting the current from the overhead conductor, or operation with batteries. If desired the two systems may be combined, thereby allowing the trolley to be brought into use through the galleries equipped with the overhead system, and switching on the batteries in the other parts of the mine where the conditions do not permit the observance of the former method.

When the battery system only is employed a certain difficulty often arises. The cells occupy considerable space, and their stowage is not an easy matter, if the retention of the feature of accessibility to the mechanism for inspection and oiling be desired. At the locomotive station the disposal of the batteries does not occasion any anxiety, for the simple reason that by means of a small crane the battery section intact can be lifted clear of the locomotive, but on the road it is sometimes necessary to open up the mechanism, when the obstruction extended by the battery is likely to prove a serious matter. In this mining locomotive operating on accumulators the difficulty is ingeniously overcome by mounting the battery box—which is superimposed upon the locomotive frame—upon a pivot. Should it become necessary to oil-up or inspect on the road, the driver merely swings the battery box round on its pivot. The mechanism is thus bared, and inspection, adjustment, or lubrication may be completed as readily and easily as in the ordinary trolley locomotive.

SPEEDING-UP THE COAL OUTPUT.

A 20-ton six-wheeled triple-motor "Jeffrey" locomotive making speed with a heavy haul through the main gallery of a mine. A locomotive of this type can draw a load of 333 tons upon the level, and 51 tons up a gradient of 1 in 17.

The battery locomotive, either in the direct or combined form, is useful for what might be termed auxiliary and emergency duty. Owing to the installation of the battery it can gather cars from the rooms, compose the train for the main haul, then move this train out on to a siding and leave it there to be picked up by the main

heavy-duty locomotive. In the rooms, low speed on the part of the tractor is desirable upon occasion, and this can be fulfilled advantageously with accumulators, inasmuch as such operation is easy on the controller resistance and the track. Finally, the main haulage locomotive may suffer delay, or require an adjustment to be made, thereby compelling withdrawal from service for a brief period, or the overhead system may fail. To ensure that car-filling shall continue without interruption, or to avoid congestion of laden cars upon the siding, the battery locomotive can be run out on to the main system and take up the general service until the main-haulage locomotive is returned to duty or the overhead system is repaired. Moreover in some mines the danger from gas is so great as to prohibit the employment of a trolley locomotive, owing to the risk of sparking between the trolley and the conductor. But the battery locomotive can be employed in perfect safety. The accumulators merely constitute an accessory, and need not necessarily interfere with the design, constructional features, and equipment of the locomotive in any way.

The Pony wholly Superseded

In some mines where electric traction has been adopted the animal has not been wholly superseded. The pony is retained for gathering the loaded cars from the rooms, hauling them from the coal-faces to the partings, and making the return journey with empty vehicles. But this necessity for animal power for such duty no longer prevails. What are known as gathering electrics have been devised for this service. They are smaller editions of their powerful big brothers, weighing only from 4 to 6 tons, while they are more squat and compact, the top of the body being practically flush with the top of the wheels. The gathering locomotive may either be of such a character as to enter each room and approach the working-face to collect laden cars or to return empties, or it may be a crab locomotive, which does not enter the room, but hauls out the laden cars from a point near the entrance to the room by means of a flexible wire rope mounted upon a reel on the rear end of the locomotive, and driven by the motor of the latter.

The Cable-reel Locomotive

The electric cable-reel locomotive has proved eminently serviceable. It requires little headroom, the driver being seated very low, and so can enter low veins. It will penetrate places impossible of access by animals unless the haulage way be sufficiently high to permit the pony to pass, often a very laborious and expensive provision.

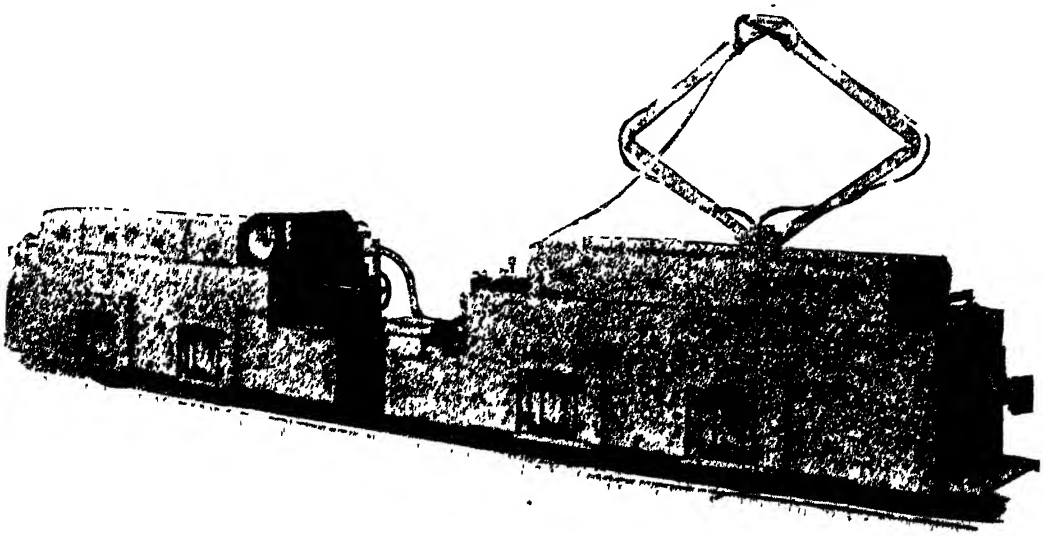
Upon the front of the locomotive is mounted a reel upon which is coiled duplex cable, and the reel is either electrically driven in a direct manner by an independent motor, or by mechanical drive through gear carried on an intermediate shaft of the locomotive motor. If metal rails have been laid up to the working-face, the cable is made fast by means of a hook to the end of the overhead conductor system; the rails are used for the return circuit in the usual manner, and the cable is kept taut by its winding mechanism. As the locomotive moves to and from the working-face this cable is paid out, or wound in, the tension being constant.

On the other hand, if wooden rails be employed in the room, the current for the motors is obtained by hanging one end of the duplex cable to the end of the trolley wire, while the other end is connected to the rail. The current flows through this electric conductor to the metal parts in the reel and to the motors and controller. To meet the conditions, where it is desirable for the locomotive to enter only some of the rooms, the features of both the crab and cable-reel types are combined in the single unit. The cable-reel, although not so generally economical as the storage-battery

locomotive, is cheaper than animal power; while it is the most efficient device for gathering coal in those mines where grades are heavy, the hauls long, and the trips severe. On the other hand, where the average grades are relatively easy and the haul is not too long, the battery locomotive reduces the cost of operation somewhat markedly.

The battery unit is to be preferred because it is wholly self-contained. It resembles the steam locomotive, in that it carries its energy-producing unit with it. It is simple to control because its operation is not restricted by considerations of cable length as in the cable-reel system. No overhead conductor system, feeder, bonding and flexible wires with their attendant expense are incurred. In so far as comparison with animal power is concerned the storage-battery locomotive is inestimably superior. It can do the work of three to four mules, does not break up the road surface as is the case with the iron-shod feet of the ponies, and reduces the expenditure on account of drivers, feed, harness, shoe renewal, depreciation in value, and hospital upkeep.

An American zinc company installed one 4-ton storage battery locomotive of 24-inch gauge in its mine at Mascot, Tennessee, thereby displacing three mules. This locomotive is used on a haul of 1,000 feet, and it handles the whole of the output in 15 round trips, with a train composed of 8 cars. This duty is completed on a single charge of the 63 Edison cells having a capacity of 17 kilowatt-hours. In this case increased output of the unit is secured, as, for instance, when required to run a night-shift, by the provision of crane facilities for the removal of the box complete with exhausted batteries from the locomotive, and the substitution of a similar charged set, that which has been withdrawn being connected up to the charging board.



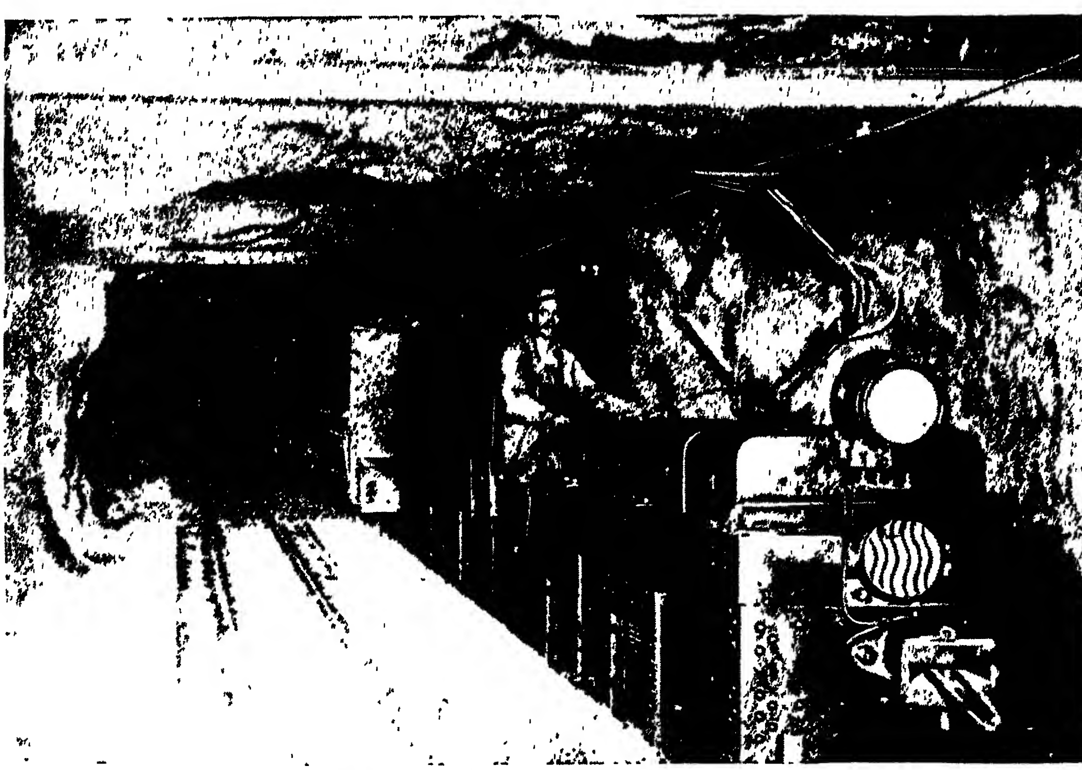
A NOVEL "TANDEM JEFFREY" ELECTRIC LOCOMOTIVE USED IN THE ARIZONA COPPER MINES.
Owing to the gauge being only 20 inches, and the duty arduous, the locomotive had to be built in two units, each weighing 6 tons, and coupled together in the manner shown for one-man control.

A gold-mining company was also confronted with its haulage problem, tramming in the usual manner over the 18-inch gauge track being considered too costly. Thereupon a 3-ton storage-battery locomotive was installed as an experiment. This unit was called upon to do double duty with a change of battery at the end of each 8-hour shift. On a single battery charge

the unit, coupled to a train of 10 cars weighing 2,250 lb. each, makes 24 round trips in moving 7½ tons of ore per trip over the haul of 800 feet. So marked was the economy of haulage by this means that two additional locomotives were put into service.

Economical haulage over a track of narrow gauge, as for instance 18 inches, has developed into a serious problem in many mines, owing to the rising costs. Conversion of the track to wider gauge is not possible, because it would involve the abandonment of the existing rolling-stock, and prevent the double trackage through some of the galleries. The Arizona Copper Company experienced this difficulty at the Morenci mine; moreover under the prevailing conditions specially heavy equipment was essential. To meet the situation, the double-motor type of locomotive was evolved. This comprises the construction of the locomotive equipment in 6-ton units, each complete in itself, but two of which may be coupled together to secure one-man control.

This arrangement has satisfactorily overcome the difficulty of providing adequately heavy locomotive equipment for very narrow gauge. In such a mine as this it was especially appreciated, because the widening of the tunnels through the solid rock to accommodate two tracks of wider gauge would have involved extremely heavy expenditure. Satisfied with the efficient showing of the tandem arrangement, the mining company extended its electric locomotive stable to three of these 12-ton tandem units with lighter motors than were furnished with the initial two tractors. In addition to these it is operating eight of the 6-ton single units in



A 12-TON "JEFFREY TANDEM" LOCOMOTIVE HAULING A HEAVY LOAD OF METAL ORE

Electric traction in the underground workings of the Morenci mine of the Arizona Copper Company was rendered possible only by the adoption of the narrow-gauge two-coupled locomotives. This mining company favours both single and tandem units; several of each type are in constant service. These electrics have an overall length of about 11 feet, are 40½ inches in width, and 48 inches in height.

lighter traffic. It may be mentioned that both double and single units operating in this mine are equipped with "straight" air-brake systems. Coupling two engines together in this manner, thereby transforming them into a single locomotive, increases the overall length of the electric mule to 11 feet.

Heavy-duty locomotives, ranging from 17 to 30 tons in weight, are doing striking service upon the American anthracite and bituminous coal-fields. They are engaged in both underground and open-air traffic, and the loads are hauled in this manner direct from the gallery in which the trains are made up to the screens and cleaning plant. All units exceeding 15 tons in weight are fitted with six wheels. This arrangement renders the locomotives easy on the track, and allows the employment of light rails. The heaviest "mules" that is, the 30-tonner type, are fitted with three motors, the weight being distributed over the six wheels. In some instances the outside hauls are relatively long, one being $2\frac{1}{2}$ miles in length, and having a grade rising 1 in 40. On one such haul with this grade the 30-ton locomotive regularly handles 32 trucks and maintains a speed of about 8 miles per hour.

The employment of the electric locomotive—which is also meeting with increasing favour in Canada, France, Germany, Austria, and other countries where the mining industry is of distinct importance—is conceded to represent one of the most financially successful and efficient applications of electricity to the mine. It is rapidly displacing the pony, where the conditions are favourable, and no one will regret that animal power is being relieved from life and labour underground.

COMING OUT OF THE MINE.

Where the colliery is driven into the side of the hill the conditions are favourable to the direct movement of the coal from the working-face to the cleaning machinery by electric haulage. In the above illustration a "Jeffrey" 10-ton locomotive is bringing out a load of 150 tons of coal.

THE WATER-POWER WEALTH OF THE WINNIPEG RIVER.

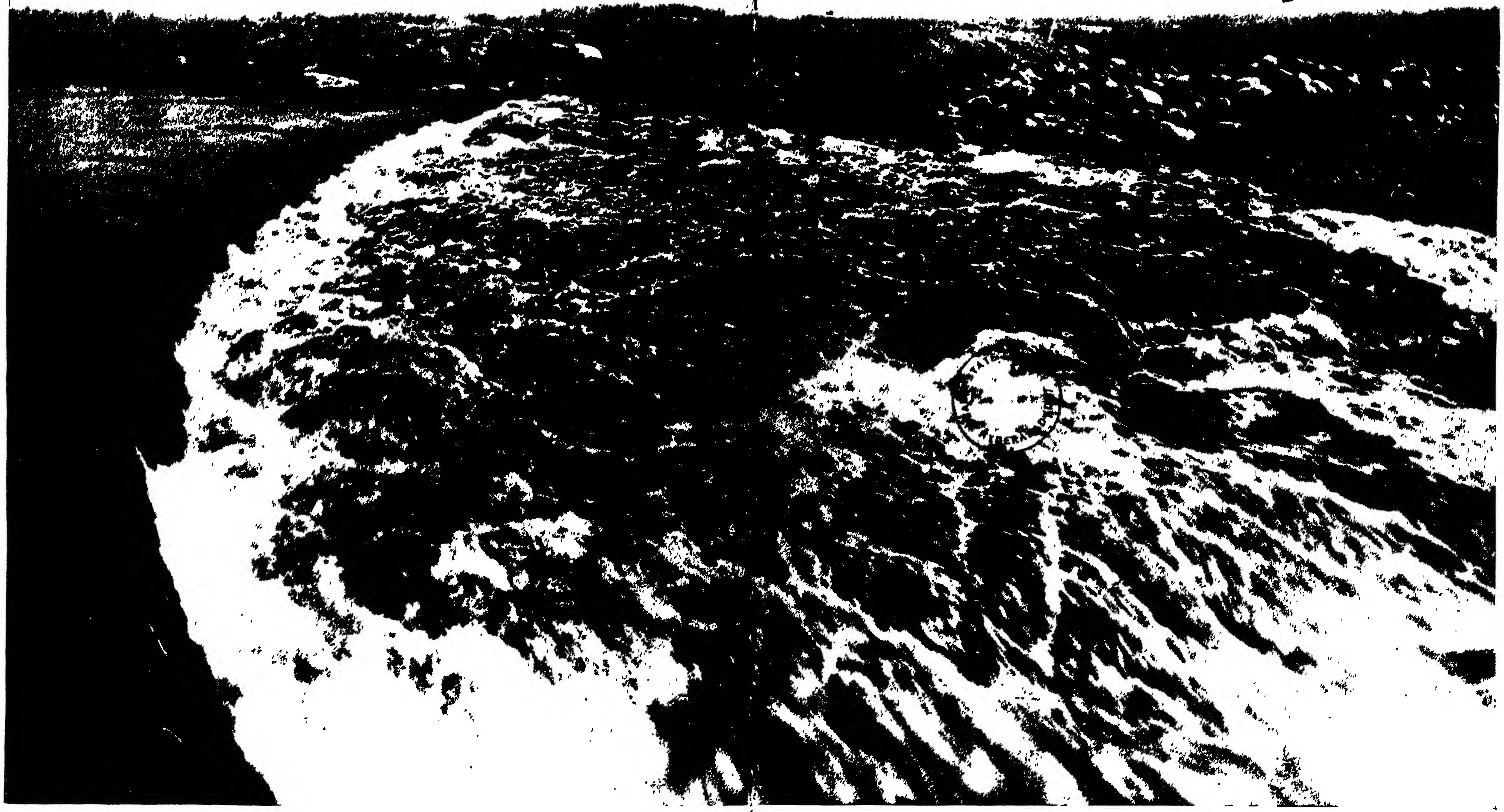
The Point du Bois Falls, from which 112,000 horse-power is ultimately to be derived; 68,000 horse-power is already being taken by the municipal installation of Winnipeg. This river drains 55,000 square miles, and has a dependable flow of 20,000 feet per second.

The World-wide Search for Water-power—II

SOME DIFFICULTIES OF THE HYDRO-ELECTRIC ENGINEER

THE installation of a plant to turn potential energy, as represented by a waterfall, into electricity appears to the lay mind as a comparatively simple and straightforward undertaking. This impression is doubtless due to the relative facility with which some of the power at present running to waste in this form has been trapped and compelled to render service. But the power-station is only the visible product of a vast amount of preliminary labour of the most searching character, spread over a long interval of time. Before a site can be definitely selected a mass of technical data has to be gathered, bearing upon such factors as "precipitation," "stream-flow," "run-off," "evaporation," and "discharge"—issues of obscure significance to the uninitiated, but vital to the hydro-electric engineer. Incidentally, it may be mentioned that the operations of this creative mind have been responsible for the evolution of distinctive terminology which, while freely used, is only indifferently and possibly hazily understood by the average individual.

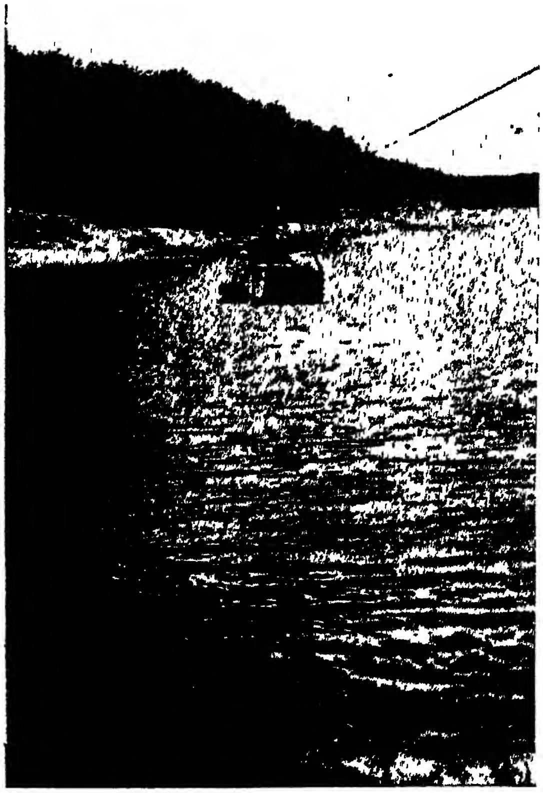
The survey of potential water-power is not confined to the observation of the actual waterway or fall concerned. The whole district or watershed drained thereby has to be investigated, and this work often involves penetration into and exploration of little known, even inhospitable country, or wandering over a vast tract of sparsely



SURPLUS WATER RUSHING OVER THE SPILLWAY OF THE CITY OF WINNIPEG MUNICIPAL POWER-STATION AT POINT DU BOIS.

This photograph conveys some idea of the Winnipeg River when in flood. The flow of this wonderful waterway ranges from a minimum of 11,000 to 64,000 feet per second, although, according to the high-water marks, the enormous flow of 100,000 feet per second has been attained. Two installations have been completed, drawing 103,600 horse-power—the hydro-electric station of the City of Winnipeg utilizing 68,000 horse-power, and that of the Winnipeg Electric Railway Company 35,600 horse-power. When the municipal scheme is completed 112,000 horse-power will be harnessed.

settled territory. The task teems with adventure and excitement rivalling that of the engineer probing the country in search of a route for the railway. In the heavy mountainous parts of the world the work is probably more thrilling and dangerous,



HOW THE HYDRO-ELECTRIC ENGINEER DISCOVERS WATER-FLOW

Cable "metering" station at Slave Falls on the Winnipeg River. The instrument for recording the velocity of the water has been lowered into position, and the operator is taking the readings.

because the hydro-electric engineer must necessarily scale the heights to gain the sources of the various rivers under investigation, in order that he may glean all that can be learned concerning the run-off and extent of the drainage area, as well as to collect information bearing upon the carrying out of such development works as will be necessary to conserve the supply.

The hydro-electric engineer may almost aptly be compared with the mineral prospector. His impedimenta must be reduced to the minimum to facilitate movement in spying out the land. A pack-horse or two will carry the whole of his worldly goods, as well as ample supplies of food, and he may be engaged in the heart of the mountains for weeks on end without a word of his whereabouts reaching his base; or it may be necessary for the reconnaissance party to keep to the rivers. In this case advance is made foot by foot by canoe or whatever means of transport, no matter how primitive, may be available. Rapids, falls, variations in the width of the river, the changing character of the banks, the fluctuating velocity of the water—all are observed in detail. Records pertaining to the highest level attained by the water during times of flood, and lowest level reached in time of drought, are sought. The recollections of the local residents, and, if any, traces of old water marks are noted, because they bear upon the great issue.

When the hydro-electric engineer is called upon to conduct such a survey as that of the basin of the Winnipeg River, he is confronted with a gigantic trek. The basin in question has an area of 55,000 square miles. It is riven in all directions by waterways linking up an imposing network of lakes serving the large central reservoir known as Lake Winnipeg, which discharges the whole of the water it receives into the Nelson River flowing north and emptying into Hudson Bay. This is probably one of the most uninviting areas of the Dominion of Canada. Despite the circumstance that this basin lies between the Great Lakes and the extensively developed wheat belt of which the city of Winnipeg constitutes the strategical portal, it is sparsely settled, mainly because it presents no agricultural, and slender industrial, attractions. The survey of this territory also

emphasizes how the search for water-power, and the consideration of the vital factors, are likely to bring one into conflict with opposing interests. Not only does this basin sprawl over the two Canadian provinces of Ontario and Manitoba, but it is traversed by the International Boundary, 11,000 square miles lying on the American side of the frontier.

Winnipeg's Developments

When the city of Winnipeg began to assert its commercial importance and the inevitable demand for cheap power arose, this basin became the hunting-ground of hydro-electric engineers seeking sites for power-stations. The first investigations, from the electric generating point of view, were made in 1895, and the first practical effort to turn the wasting water energy to account was made in 1906, when the Winnipeg Electric Railway Company established a power-house on the Pinawa Channel, using a head of 39 feet to generate electricity to drive the tram-cars in the city 65 miles away. Five years later the civic authorities embarked upon a municipal undertaking of a similar character, establishing the necessary power-house at the Point du Bois Falls on the Winnipeg River, where a head ot 45 feet was available, and transmitting the current thus produced over the intervening 77 miles to the grain metropolis.

The preliminary investigations identified with these two schemes were of a severely local character, but the sustained demand for power emphasized the urgency of a complete survey to determine the exact capacity of the basin as a whole. The fulfilment of this task occupied four years, that is, so far as the field operations were concerned, but much of the work thus initiated has to be continued from year to year. This is particularly the case in regard to the observations concerning flow of water and run-off.

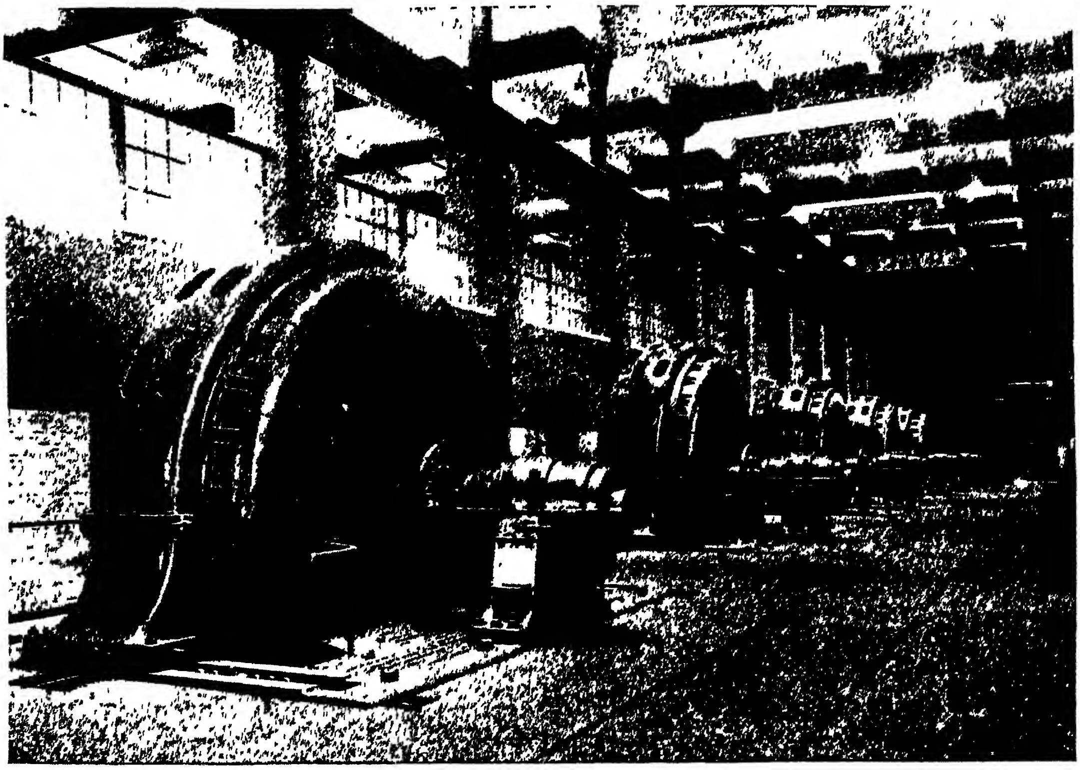
The readings of the flow—a task of decisive significance—are taken at several points, "metering" stations being established for this purpose. The stations are planted, so far as conditions will permit, in straight sections of the waterway, where the river bed is smooth and where there are no cross-currents or backwaters. The method of taking the readings varies. A cable may be stretched across the waterway to serve as the track for an aerial "basket" or car accommodating the observer and his instruments. A boat may be held stationary in the channel at a preselected point. Emergency methods are also freely called into operation, involving even wading up to the thighs, or boring holes through the ice for the manipulation of the recording devices.

The permanent station is generally established upon cable-lines, this representing the simplest and most efficient means of gathering the required data. By means of the instruments used and successively employed at various points and depths in the channel, the observer in the car discovers fluctuations in the volume of the water as well as changing velocities. The recording instrument, lowered from the cable-car, is held stationary for a predetermined interval of time. The velocity readings obtained in this way may vary widely, but the readings are struck for the guidance of the engineer.

The Pioneer "Miner's Inch"

The metering station will give the rate of continuous flow in "second-feet,"* as it is termed. These readings, as may be anticipated, enlighten the engineer as to the run-off—that is, the depth to which the whole of the tract drained would be covered if all the water could be conserved and distributed. The run-off is compared with the precipitation of rain or snow, or both, over the selfsame area and is expressed in inches. In certain parts of the world another form

* The unit "second-foot" represents the flow of water through a channel 1 foot wide by 1 foot deep in one second.



SAFEGUARDING THE GENERATORS AGAINST FLOOD.

Electrical bay of Power-house No. 2 of the Shawinigan Water and Power Company, of Shawinigan Falls, Quebec, showing battery of five 20,000-horse-power generators. These are coupled direct to the water-turbines, but are separated therefrom by the massive wall which acts as a bulkhead in the event of a water invasion.

of calculation is recognized. This is the "miner's inch,"* a survival of the pioneer mining days when the absence of standard measuring facilities demanded the extemporization of a means to this end capable of ready application and acceptance. The solution which came into general vogue throughout the mining districts has never been completely superseded in the allocation of water to permit a miner to pursue his operations. Wherever this form of measurement survives it is generally determined by local statute to avoid dispute, although in many instances the equivalent in second-feet or gallons per minute is expressed simultaneously.

The necessity to gather definite data by scientific means will be realized when it is stated, that during the course of the year the maximum may be found to exceed the minimum flow fivefold or sixfold, or more. Thus, the observations spread over a period of eight consecutive years at the metering station established at Slave Falls on the Winnipeg River, revealed a maximum mean for one month of 52,820 second-feet, while the minimum mean for a month was 12,340 second-feet. These were the extremes. The circumstance that the flow fell to as low a point as 12,340 second-feet revealed to the engineer the most unfavourable water conditions with which he would have to contend in the preparation of his plans.

Incidentally, the necessity to pay due respect to the memories of the "oldest inhabitant," legend, or primitive flood-

* The "miner's inch" is the volume of water which will pass through an opening 1 inch square under a certain head, the last-named factor being governed by local conditions.

marks made by settlers and natives in a locality under survey was emphasized during the investigation in question. The survey party found flood-marks from which it was evident that a flow of 100,000 second-feet had been attained. It seemed to be an impossible figure, but it demanded investigation, inasmuch as the engineer must also be prepared to cope with an abnormal level due to some cause which defies control.

The flooding of a power-station is not such a remote possibility as one might perhaps imagine. Many sudden and extraordinary rises of water have been recorded, and a flood is capable of wreaking widespread havoc in a hydro-electric station. Should the water reach the electrical apparatus it may ruin it irretrievably, bringing about cessation of operations until the machinery can be replaced. In the modern power-house every precaution against the water breaking bounds is taken. At one of the stations operated by the Shawinigan Water and Power Company, in Quebec, the bay accommodating the hydraulic machinery is isolated from that in which the electrical plant is installed by a wall carried to a sufficient height to form an effective barrier against the maximum unimpeded flow through one of the 14-feet penstocks should the water be accidentally precipitated into the station. In the event of such a contretemps the incoming rush of water would be given free escape through the doors, windows and other openings available. It would be immaterial how the water got away, so long

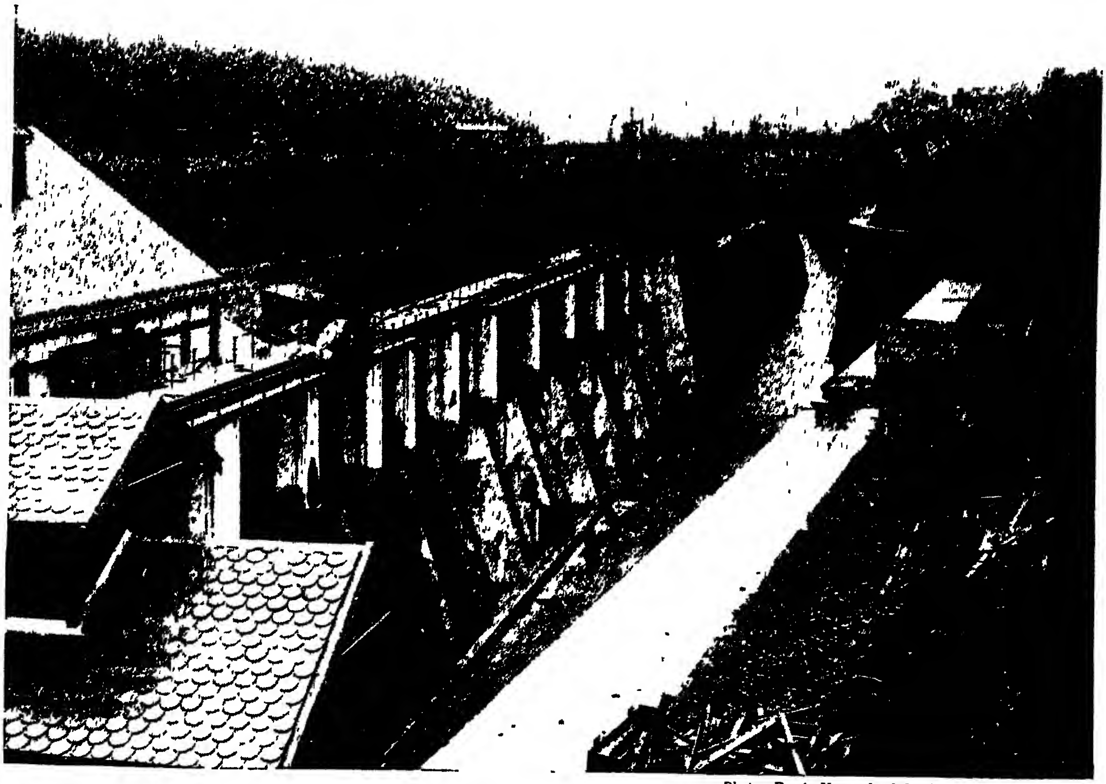


Photo E A Vormals Schuckert & Co, Christiania.

PROTECTING THE TURBINES AT THE GLOMMEN HYDRO-ELECTRIC STATION.

The intake to the power-house, showing racks and screens erected to prevent the entrance of floating debris brought down by the water through the canal, which, unless intercepted, might enter the turbine-casings and damage the wheels.

as it made its escape and left the electrical plant unscathed.

It is not always possible to plant the power-house in such a position as to secure complete immunity against flooding. The tail-race might become blocked with ice or some other obstruction, causing the water rushing through the turbines to bank up and submerge the station before the supply could be intercepted. To meet such eventualities many stations have all exposed doors and windows fitted with seats for the reception of stop-logs—baulks of timber—which are kept conveniently to hand for such an emergency. At the first sign of rising water all hands in the station rush forward to improvise the barricade, and in this manner the invasion can be stemmed effectively. In hydro-electrics water is an admirable servant, but if it should succeed in securing the supremacy, even for only a brief period, it becomes a tyrant indeed. This is the reason why the plotting engineer, when spying out the country, is always ready to listen to local gossip and the tales of old men and women about remarkable floods. Naturally, these tales are sifted, and endeavours made to obtain corroborative evidence. If the engineer should fail to receive adequate supporting testimony he does not dismiss the stories as mere yarns. The very fact that they have gained circulation is sufficient to indicate that something out of the ordinary must have happened. Accordingly, he extends them every respect, on the principle that it is better to be safe than sorry.

Danger from Flood

The engineer also has to gather conclusive data relative to several other issues which may appear to have no bearing upon the subject. He must take into consideration the geological, climatic and forestal conditions of the territory surveyed. A district may extend every promise of yielding an abundant supply of water owing to the heavy rainfall. Superficially it appears as if such precipitation would be adequate to satisfy all desired requirements, even during the trying period of the summer months when the flow of the streams sinks to its lowest level. But experience has taught, notably in the State of California, which is exposed to a heavy wet season, that the contribution of rain during such periods is by no means a reliable index to the minimum flow of the waterways during summer.

In the state in question it has been found that the minimum flow is fairly uniform summer after summer, irrespective of the rain contribution during the preceding wet seasons, in those watersheds where numerous old river channels and lava cappings exist. If there be massive rock formation, without ancient water channels, then the run-off is almost immediate. The old channels of the North Yuba watershed absorb a tremendous volume of water during the rainy season and store it underground. When run-off has ceased—that is, all the surface water has escaped—and the summer sun holds sway, this subterranean reservoir commences to surrender its stock. The result is that in this watershed the contribution of water is strikingly uniform summer by summer. The only braking effort is that exercised by the temperature, due to solar influences, during the hot season.

Temperature, consequently, plays a vital part in the solution of hydro-electric problems, and extreme hard weather in winter is able to exercise just as decided an adverse influence upon the flow as intense summer heat. In the Winnipeg River basin winter temperatures of 40 degrees below zero—72 degrees of frost—are frequently recorded and often prevail for long periods. The inevitable corollary of low temperature is the ice, and this is probably the most perplexing of all factors influencing this

Effect of Temperature

craft, particularly in northern climes such as Canada and the United States. The low reading of the thermometer reduces the run-off and freezes all small streams solid.

Ice assumes three forms, which occasion the utmost anxiety to the hydro-electric engineer. These are known as sheet or surface, frazil and anchor ice respectively. The first is the most familiar, because it is the winter armouring to our lakes, ponds, and comparatively quiet waters. It is likely to exert enormous pressure upon the masonry structures erected to impound and control the flow of the water, and to precipitate floods and water shortage when breaking up in the spring. The broken masses of ice, impelled by wind and current, are liable to pile in a solid inextricable mass, or jam, damming back the water. Should the obstruction occur below the power-house, then the discharge through the tail-race is likely to be impeded with the attendant risk of flooding the station unless the solid wall be breached with dynamite.

THE HYDRO-ELECTRIC ENGINEER'S MOST REMORSELESS ENEMY.
Winter conditions, with heavy ice below the spillway, at the power-station of the Winnipeg Electric Railway upon the Pinawa Channel of the Winnipeg River. Ice accumulation below the power-house is apt to cause a rise in the level of the river and thus menace the turbo-generators. To ensure free discharge of the water, the engineer has to resort to dynamite to blast the obstruction away.

The pressure which ice is able to exert may be appreciated when it is stated that the allowance therefor, in the construction of dams in districts exposed to severe winter conditions, varies from 24,000 to 40,000 lb. per lineal foot at the highest ice-line. Although the heavy ice covering the water will freeze solidly to the surface of the dam, and will set up severe strains, especially when accompanied by a drop in the level of the water beneath, it is the break-up of this armouring which perturbs the engineer. He knows full well that the broken masses of ice will collect to form an impenetrable barrier, and consequently compel the level of the water behind to rise to a dangerous degree. There is always a healthy struggle between the ice jam and the imprisoned water for supremacy. The moment the power-house engineer detects signs of formation of a jam, the power-station staff grows apprehensive and active. Dynamite is an excellent persuasive with which to intervene on the side of the pent-up water, and when liberally applied in imposing doses will invariably subdue the most refractory ice-wall.

Anchor ice is of a different character. This is formed upon the bed of the waterway by the radiation of heat from the river-bed to the colder air above. On a clear cold night it forms very rapidly. This ice causes trouble because it ultimately tears itself free from its anchorage to rise to the surface, and in its escape bears with it embedded boulders of considerable size

which, if permitted to effect pounding action under the combined forces of wind and current, may wreak considerable damage.

Nevertheless, while the surface and anchor ice are regarded with apprehension because they may or may not cause trouble, it is the frazil or slush ice which is the despair of the constructional engineer and his colleague in charge of the power-station. In this form ice is liable to promote a whole peck of troubles. The ice-crystals grow and accumulate rapidly, adhering to one another and attaching themselves to every cold body encountered, in the form of huge lumps and spongy masses. Disturbed water conditions and prolonged periods of intense cold are favourable to the formation of this ice, and it will often accumulate to a depth of 30 feet or more, completely blocking the water channel and lifting the level of the water.

At some power-stations a regular routine of blasting operations has to be observed during the winter to keep the approach to, and discharge from, the plant clear of this enemy. The ice is so tenacious that it will seize and establish a grip upon the screens disposed in front of the tunnels to the penstocks, the penstocks, and even the turbines themselves. There is scarcely a power-plant in a cold climate which has not suffered from this relentless foe in greater or lesser degree.

THE ENGINEER'S CHECK AGAINST ICE

Ice-racks at the entrance to the turbine pits of the City of Winnipeg Municipal hydro-electric station. The channel on the right is packed with broken ice brought down by the incoming water.

Fertility of thought is in constant demand to defeat the machinations of the frazil ice. The constructional engineer must devote close study to the local situation and conditions so that he may set his station at the point least exposed to this danger. By the disposition of booms the drifting ice may be deflected from the forebay, whence the water is drawn through the penstocks; but even then masses are almost sure to creep under this defence and, owing to the suction, gather round the screens, thus impeding the flow of the water. In this event the masses essaying this guerilla warfare are attacked by men armed with long poles, who dexterously divert the drifting masses to a convenient channel, whence they can be carried clear of the screens.

The penstocks and the casings of the turbines form excellent bases for the formation of the frazil ice owing to the lower temperature of the iron. The screens form another attractive anchorage and propagating medium, especially if the ironwork be carried above the water-level. In some instances the tendency for the ice to form upon this foundation is thwarted by heating the sections of the racks above the water-level by electricity or steam. The heat radiating through the metal to the

HOW WINTER HARASSES THE HYDRO-ELECTRIC ENGINEER.

Devil's Canyon Dam in the grip of King Frost, showing ice collected upon the spillway. On the right is the sluice, which is almost completely obstructed by ice and snow. Fortunately, among the Canadian Rockies, winter conditions coincide with minimum water flow, so that risk of flooding is remote. The danger arises with warm spells and the approach of spring, when a heavy run-off may be anticipated.

submerged portions will prevent the ice forming or effecting a grip. At the Shawinigan plant an elaborate heating installation has been laid down, the racks protruding from the intake as well as the water entering the screen-house being exposed to a steady sustained blast of hot air.

Reverting to summer conditions we find the engineer confronted by another adverse factor—evaporation. This is usually the cause of the heaviest loss to the run-off from any watershed. In one instance, relating to a large basin in the temperate zone, the hydro-electric surveyor discovered that the loss through evaporation during the summer season was equal to the total rain precipitation. During a period of seven months a fall of 17·5 inches of rain was recorded, but the sun retrieved 17·18 inches during the self-same span of time. What evaporative losses signify may be realized when it is stated that such an evaporation as 17 inches over the surface area of a lake 1,500 square miles in extent is equal to a continual discharge of 10,000 cubic feet of water.

Costly Development Work

The hydro-electric engineer has to study the problem of water-power, involving such a diversity of antagonistic factors, from many apparently conflicting angles. But the main burden of his labours reduces to the determination of one simple factor—the minimum flow recorded during the year. No demand for power can be entertained which is in excess of that possible of generation during the driest part of the year. The variation between maximum and minimum flows being so extreme, the engineer endeavours to maintain the average supply by supplementing the deficiences of Nature with artificial creations, such as the provision of storage lakes and reservoirs upon the headwaters; and it is the carrying out of such development work which is so costly. In California it is necessary, in many cases, to provide sufficient accommodation for water to last from 180 to 210 days out of the 365, and thus secure the essential daily supply of energy to the power-house for the maintenance of the desired output of electricity. As is well known, the Californian rivers are born of the snows capping the peaks of the lofty Sierra Nevada mountain range. The rainy season swells their volume to excess, but during the dry spells it is the melting snows which sustain the water flow.

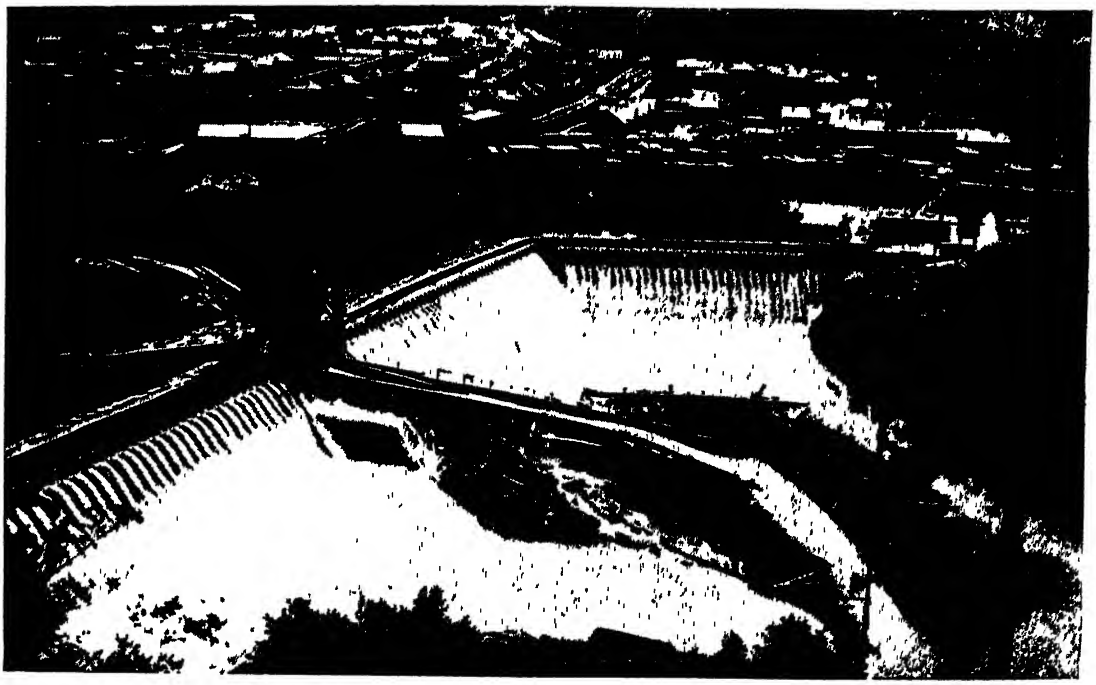
Most Favourable Watersheds

The most satisfactory results are forthcoming from those watersheds in which the tree growth is sparse. Snow does not accumulate so rapidly in timbered districts as upon bare ground. Vegetation presents only one advantage from the hydro-electric engineer's point of view: it delays the run-off, or, rather, militates against its speedy completion. On the other hand, snow transformed to ice on barren soil melts much more slowly and furnishes a run-off for a much longer period, which is one reason why glacier-born rivers are generally impounded or tapped in preference to any other. Their contribution of water attains its maximum during the hot summer months when the sun's rays are most powerful, and when all other sources of supply are likely to be at their lowest ebb.

Reservoir construction in high exposed altitudes, where the mountain flanks are severely scarred and torn, is inevitably costly. The sites, for the most part, are far removed from the beaten tracks which frequently have never been trodden except by some venturesome mountaineer. To increase the storage capacity of Huntingdon Lake, lying 7,000 feet above the Pacific, to 53,000 acre-feet, in order that sufficient storage might be obtained to assure 120,000 kilowatts at 50 per cent. load-factor for 240 days in the year, the engineers were compelled to build a standard-gauge railway 57 miles in length to

reach the site. The building of the railway was a striking engineering achievement in itself. It traverses some of the most badly broken mountain country in the state, and has grades running up to 1 in 18. This essential communication, although completed in 157 days, involved a heavy capital expenditure before a penny could be spent in the actual construction of the reservoir.

The promoters of another undertaking selected a site above the clouds for water-storage. By the construction of a dam, a reservoir spreading over 15,500 acres, and carrying 300,000 acre-feet* of water, was created. This is the largest artificial power-reservoir in the United States, and probably will suffice for the requirements of its owners for many years to come. When its present capacity becomes absorbed it will be extended to 27,000 acres with 1,250,000 acre-feet of water by raising the height of the impounding barrage. Is it surprising, therefore, that a comprehensive hydro-electric scheme of to-day involves the investment of millions sterling?



THE DEMAND FOR HYDRO-ELECTRICITY AND LUMBER SIMULTANEOUSLY MET.
The chute through the dam of the Powell River Development, British Columbia, for the movement of lumber. Above the barrage may be seen the boom and gate controlling the passage of the logs over the fall into the river below.

As the hydro-electric engineer is comparatively a new-comer among those seeking the use of water, he is compelled to respect many other interests which have become established. Navigation rights must be honoured upon any river supporting traffic, and the provision of adequate locking facilities to permit vessels to pass the power-station appreciably enhances the cost of the work. Irrigation, mining and drinking-water rights must also be safeguarded. In Canada and the northern

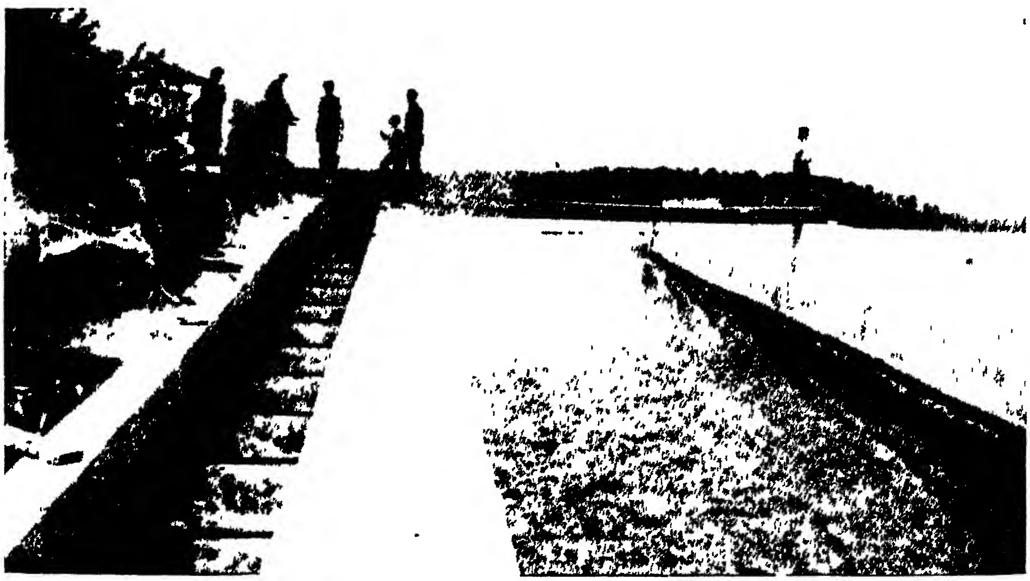
* This is the unit of measurement which has been adopted in regard to conservation reservoirs. An acre-foot is equivalent to 43,560 cubic feet, and represents the amount of water necessary to cover an acre to the uniform depth of 1 foot. It is a convenient measurement because it has definite relation to the unit of flow, one second-foot, a steady flow of 1 cubic foot of water per second representing, in the course of twelve hours, 43,200 second-feet, which is approximately equal to 1 acre-foot.

United States the lumber-jack and logging industries claim attention, inasmuch as the swiftly running and tumbling rivers constitute the highways over which the product of the forest is transported to the centres of exploitation and consumption. These industries are important, and from pioneer days have been protected by efficient legislation.

Accordingly, the hydro-electric engineer must extend ample facilities for the free movement of the logs. The end is attained by what is known as the "log-run." This is a V-shaped conduit or wide channel of sufficient depth to float the logs from the forebay above the power-station where they are collected, to the lower level of the river below the tail-race.

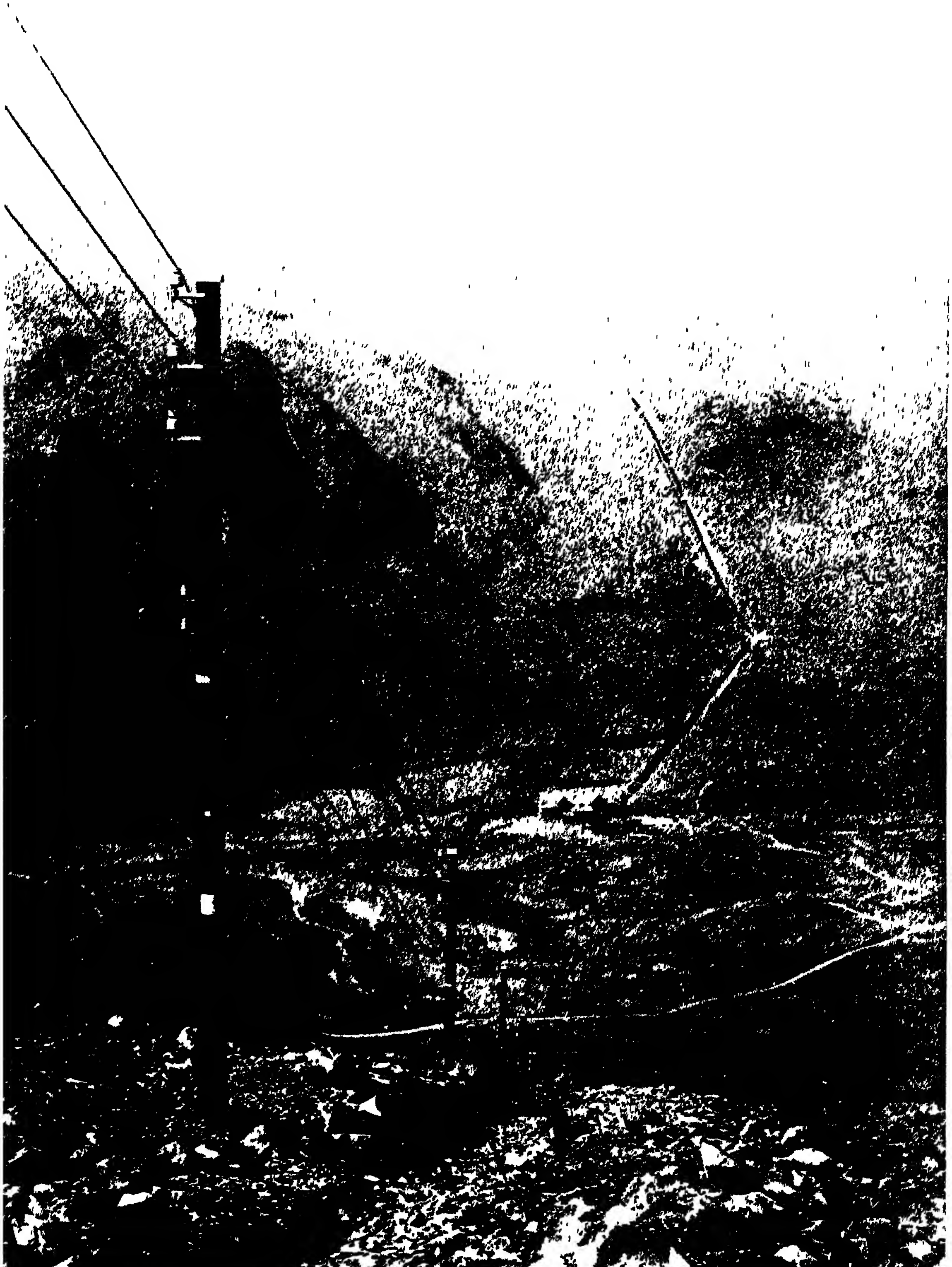
Another feature peculiar to Canadian water-power development is the fish-ladder to extend free movement to the inhabitants of the lakes and streams. Fish-ladders are installed at the discretion of the Minister of Fisheries in those instances where the power-house completely obstructs the natural channels. They are simple and inexpensive contrivances, generally assuming the form of a series of boxes, set end to end, to present, as it were, a flight of steps, the fall between the successive boxes being 10 inches. They are interconnected by openings 12 inches square, while the water also flows over the top of the partitions, thus converting the boxes into a series of pools through which the water is constantly running. The fish can move up and down these ladders without effort.

Regarded from the spectacular point of view the daring, skill, and ingenuity displayed by the engineer in harnessing the tumbling waterfall or the swiftly flowing river to provide abundant cheap electricity provokes unqualified admiration; but the impressive creations of masonry, sinuous pipe-lines, winding wooden canals, and intricate network of wires criss-crossing the country fail to present any adequate index to the romance, industry, deliberation, and the unravelling of complex tangles which, previous to the setting of a single block of masonry, engaged the keen brains of the surveyors and engineers.



A LADDER FOR FISH AND A RUNWAY FOR LUMBER THROUGH THE IMPOUNDING DAM

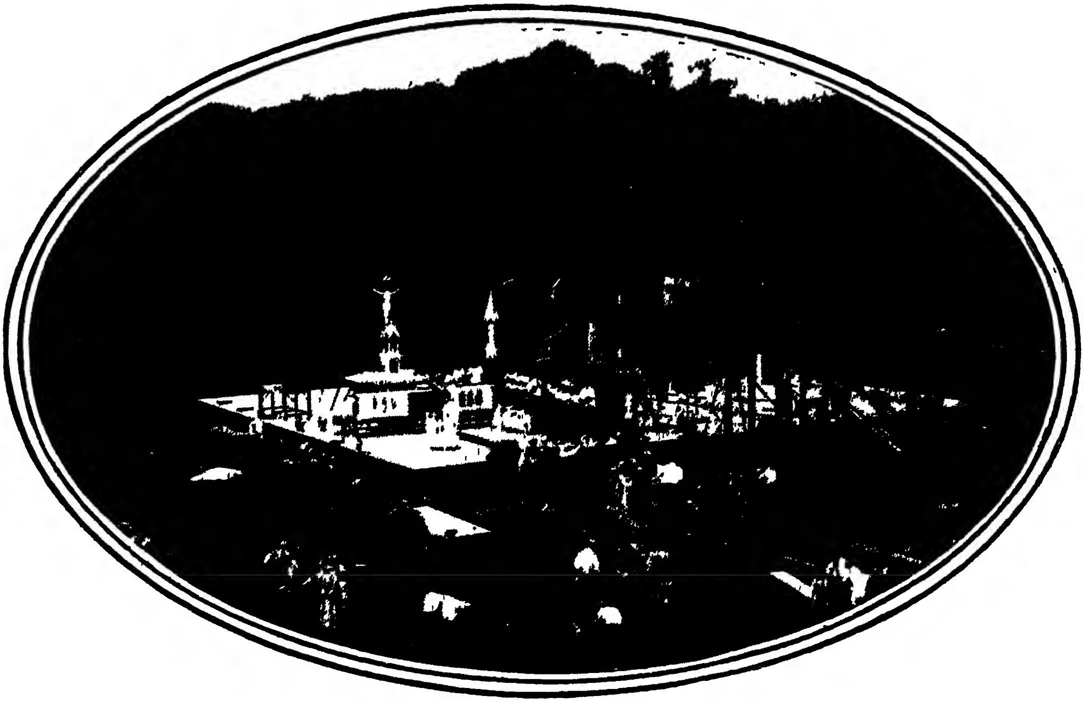
In the Dominion of Canada all established titles to the use of the water are legally safeguarded. On the right is a wide channel, which has had to be provided through the barrage to permit the free movement of lumber. On the left is the interesting "ladder," whereby fish pass easily up and down between the two water-levels.



By permission of Messrs. Bruce Peebles, Ltd.

FEEDING WELSH INDUSTRY WITH HYDRO-ELECTRICITY.

One of the transmission lines of the North Wales Power Company making its bee-line crossing of the mountains. The two lower wires, strung from pole to pole, are those of the telephone. Energy is transmitted at 10,000 volts. Across the valley may be seen the power-house and the pipe-line laid upon the mountain flank, which conducts the water from Llyn Llydaw to the turbines. Snowdon appears in the extreme distance.



THE OUTDOOR STAGE FOR SEARCHLIGHT KINEMATOGRAPHY.
General view showing two solid sets being built back to back, and, under construction on the right, the scaffolding to carry the searchlight. For convenience rehearsals were conducted during the day.

Searchlights for Moving Pictures

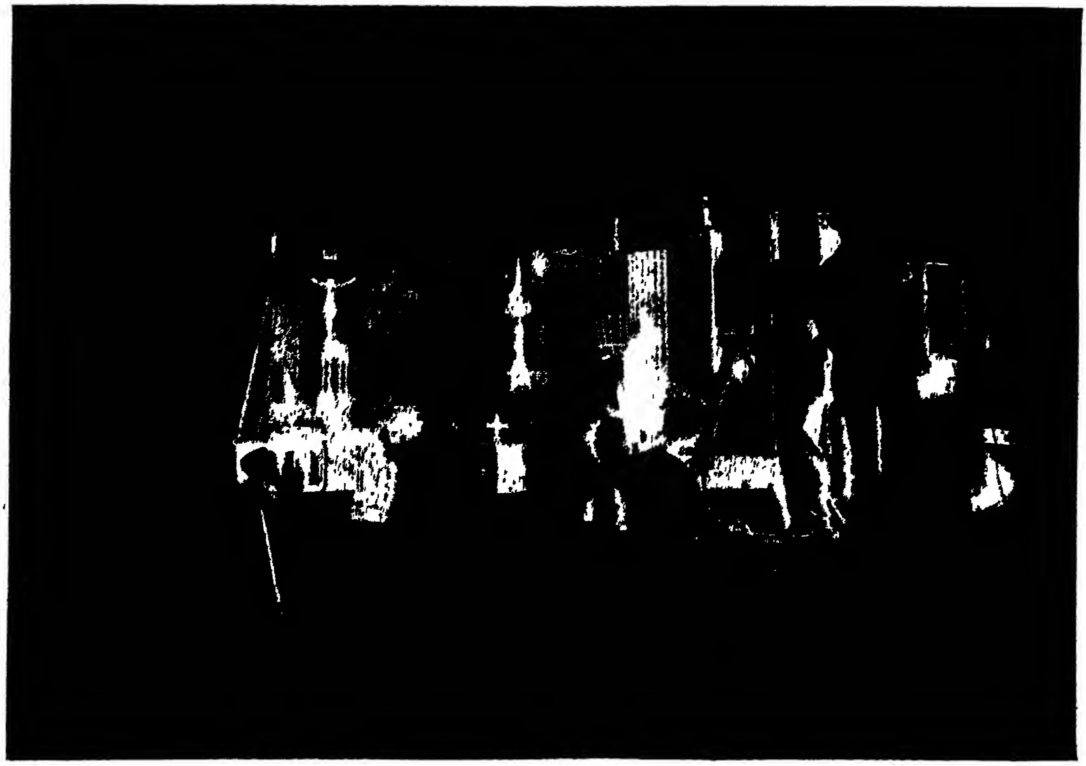
NOVEL LIGHTING EFFECTS OBTAINED IN PHOTOGRAPHING THE SCENA OF THE SILENT PLAY IN THE OPEN AIR

IN the popular mind the searchlight is generally regarded essentially as a weapon of war, to facilitate the conduct of military and naval operations under cover of darkness. But, during recent years, its application has been considerably widened. The powerful, penetrating, and brilliantly luminous beam has been discovered to possess commercial possibilities which the ingenious have been prompt to turn to distinct advantage. This latter-day utilization of the searchlight has been most powerfully emphasized in lighting-display schemes, such as the spectacular embellishment of exhibition buildings and the picturesque illumination of natural wonders for the entertainment of the visitor.

The successes recorded in the avowedly commercial fields, and the knowledge that the beam of electric light is intensely actinic, tempted an ingenious spirit to employ it upon a comprehensive scale in moving-picture photography. The purpose of this enterprising producer, Mr. Spoor, was to invest the popular story of "King Robert of Sicily" with a new interest. He was induced to take this step, not only because the searchlight presented the means to assure brilliant illumination, but because therewith novel lighting effects could be

achieved. In the presentation of the silent play it is always the element of novelty which counts.

Moving-picture photography imposes enormous demands upon electricity. So far as is practicable the producer accordingly carries out his work under natural lighting conditions. Where the climatic conditions are favourable to open-air work conspicuous success is recorded. This is the reason why California has come to be recognized as the film-play producing centre of the world. The persistent bright sunshine, combined with a clear atmosphere assures successful and perfect photography throughout the greater part of the year with the minimum of interruption. Other countries are not so favourably endowed in this respect. This is a serious disability because, should the light drop below a certain standard during the filming of the play, operations must be suspended and the whole of the personnel—artistes, stage-hands, camera-men and other members of the technical staff—condemned to idleness until such time as the light improves. Such interruptions are apt to prove expensive, especially in the case of spectacular scenarios involving the employment of hundreds of players. It is by no means exceptional, in such circumstances, for failing light to provoke a loss of £200 or more per hour.

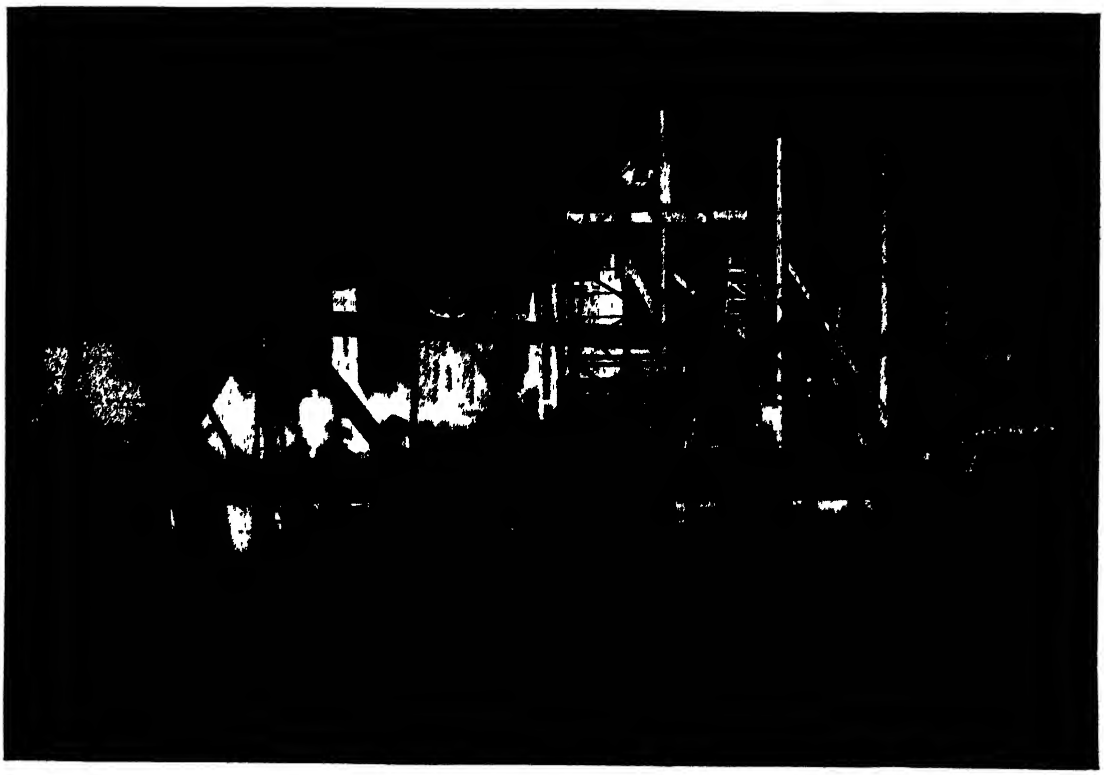


SETTING THE LIGHT.
General or flood-lighting scheme concentrated upon the scene, showing camera-artist's platform and stand for the director of production.

It was in order to be independent of sunlight that the producer resorted to the glass studio. But in order to secure the perfection of definition, detail and density, a powerful flood of light must be poured upon the scene during exposure.

Electricity is the only medium whereby these pre-eminent requirements can be satisfactorily achieved. Therefore the

kinematograph studios are equipped with wonderful lighting facilities consuming current upon an enormous scale. A small stage, measuring barely 20 feet square with its setting, may demand 80,000 candle-power, or more, to produce a satisfactory film from the photographic standpoint. In a modern well-equipped studio the stage-lighting fittings alone may represent a capital investment of £30,000 to £40,000. To ensure continuity of supply and independence, it has become general for studios to generate their own power for this purpose, and accordingly we find plants installed which are often of sufficient capacity to satisfy the lighting requirements of a town of 30,000 inhabitants.



FILMING THE PLAY.

The searchlight was directed upon the scene from a point above the set, but the projector was so mounted as to permit easy manipulation of the concentrated ray in both vertical and horizontal planes.

To the pioneer the use of the searchlight in this distinctive field provoked problems which are not encountered with the conventional illuminating methods. The searchlight throws its rays in a beam of relatively small diameter, especially at short range, as opposed to dispersion. Although it was recognized that in point of intensity of illumination no misgivings need arise, it was seen that only a comparatively small circle, or zone, could be covered therewith upon the stage. While local lighting of this character is desirable in the preparation of certain effects, such as concentration upon a main theme, it is impracticable for flood-lighting, as, for instance, when the stage is occupied by a crowd. To meet this latter requirement the producer found it necessary to supplement the main searchlight illumination with judiciously disposed and scientifically controlled auxiliary projectors of the type normally used in kinematography.

Furthermore, the pictures had to be taken under special conditions. A stage

was built in the open-air, and the filming operations carried out in perfect darkness; even moonlight was found to mar that intensity of blackness necessary to throw the pictures into striking relief. The stage was set against a background of trees.

The arrangement of the searchlights was interesting. Near the front of the stage, and facing the back-cloth (though set at a slight angle thereto), a temporary wooden scaffolding was erected for the accommodation of the main searchlights and their operators. The scaffolding permitted the projectors to be lowered or raised to any elevation desired by the producer, as well as to afford quite free movement to the right or left. Controls were also furnished to permit them to be switched on or off as required. The dispersive subsidiary projectors, to extend flood-lighting effects for certain scenes, were set about 6 feet above the stage, and on either side of the main source of light. By careful arrangement of the zones thus covered, uniform and steady lighting of the whole area was secured.

Arrangement of the Main Searchlights

One of the acute problems to be overcome was avoidance of conflicting shadows. Indeed it was not wholly subjugated. As the darkest shadow was thrown by the most intense beam of light striking the object, concentration upon the main shadow was the guiding principle. Such control of the shadows, as far as practicable, was imperative. The scenery was painted in black and white, and, owing to the brilliancy of the light, the apprehension arose that the resultant pictures would be flat, lacking tone and depth, or be harsh in contrast, whereas it was essential that relief and depth, combined with a certain degree of softness should be secured. The individual control of the projectors somewhat preserved the tone values and shadows as well as giving a certain degree of modelling, thus preserving the solidity of the set.

The cameras were mounted as near the searchlights as possible, to bring the angle of view approximately parallel to the longitudinal axis of the ray itself. In other words, the camera's line of sight was virtually along the beam of light, but of course it could not be allowed to encroach upon the latter, as in this event a shadow would have been cast upon the stage. The producer also assumed his position close to the searchlight, thereby holding a point of advantage for the issuance of instructions to the operators, relative to light control, and to the camera-men, as well as for the direction of action upon the stage.

The first attempts revealed a shortcoming which, though anticipated, proved to be somewhat more formidable than had been expected. Great difficulty was experienced in the adjustment of the intensity of the beam. The shaft of light thrown from the projector, being of such intense brilliancy, tended to "kill" all detail upon the stage. Colours lost their values; even the black tones assumed a washed-out appearance. By adjusting the power of the beam, and also the lens aperture of the camera and its shutter, this disability was corrected. Then another difficulty asserted itself. The glare from the searchlight was so dazzling that none of the players could face it. Further correction and toning-down of the beam had to be delicately carried out to reduce the strain upon the eyes of the artists.

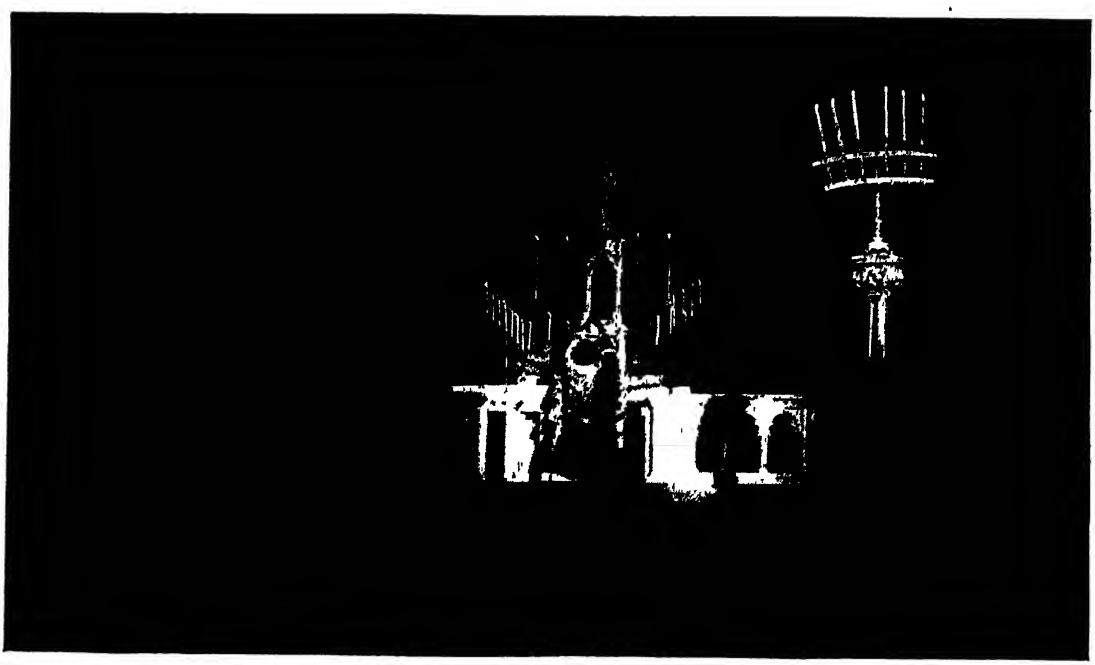
Difficulties due to Intensity of Beam

The innovation proved successful; the novelty made appeal. The lighting effects were different from any previously seen, and contributed very materially to the attractiveness of the film. The facility with which the circles of light, thrown by the projectors, were moved from point to point, and the manner in which they were induced to emphasize any desired theme or feature was eminently noticeable. The

THE STAGE UNDER FULL ILLUMINATION.
While the searchlight constituted the main source of illumination, it was supplemented by diffusing arc projectors disposed on each side to ensure the complete lighting of the scene when necessary.

contrasts, too, were striking, brilliantly illuminated objects standing out vividly against the prevailing blackness of the night, while the shadows were crisp and dense.

The application of the searchlight to



IN THE RAY OF THE SEARCHLIGHT.
The characteristic narrow zone or circle of intense light permitted concentration upon the main incident, with subdued outer fringe of light, and ultimate dissolution into the blackness of night.

TONING DOWN THE SEARCHLIGHT
Owing to the intensity of the ray from the projector, which produced harsh contrasts and a general flat appearance, supplementary lighting was introduced to impart depth to the picture, and to convey a sense of solidity and form.

picture-play production has its limitations. Action is not easy. It is not applicable to all subjects and demands, while the manipulation of the light calls for no little skill, bearing in mind that photography is so positive and quick in its revelation of faults. Again, angular lighting, that is, the projection of the ray upon the scene at an angle to the camera, is restricted unless it is desired to include the shaft of light in the picture, as, for instance, to indicate a streaming ray of sunlight, or a moonbeam through a window, because the edges of the ray stand out crisply in the picture.

Nowadays the tendency in picture-play production is to use a natural setting whenever possible; it is more convincing; but this problem is particularly acute when filming action under the huge trees of a well-wooded avenue or country road. The dense foliage shuts out the natural light and so renders the resultant pictures deficient in clarity and detail.

To lighten the prevailing gloom in order to provide adequate illumination so that the action of the players may be rendered sufficiently distinct upon the screen, and eye-strain be obviated, the producer has conceived the idea of blending daylight and electric illumination by means of the searchlight. Measures are taken to ensure that the ray will be dispersed over a wide cone to obtain the essential diffused effect. The intensity of the beam is also cleverly modulated so that it shall not clash with the natural luminosity. This flood of artificial light is thrown to illumine evenly the desired space beneath the trees, and in such a manner as to reduce shadows to the minimum. Were such to conflict with those thrown by natural

light the subterfuge would be promptly detected.

The utilization of a searchlight, even when reduced to an extreme degree, in broad daylight, may seem rather quaint, but it has served to indicate what can be accomplished in this direction under skilful scientific control.

A modification of the principle has attained a wide vogue and for a comparative purpose. This is the "spot-light." Formerly the general practice was to illumine the setting from the front, with the result that, in the case of a dark background, the figures of the artists merged into the void of the shadows. This disability could not be corrected from the front of the stage, and so it was remedied from favourable points at the rear and sides by means of a soft concentrated shaft of light. This is the illumination shed by the spot-light, and it gives a sufficiently pronounced degree of illumination to cause the artist to stand out sharply against the indistinguishable background.

When, later, the picture is seen upon the screen, no impression of the special illumination from the rear of the stage is conveyed to the uninitiated public who witness it, and the skilful employment of such a method of lighting has contributed very materially to the technical excellence of the modern picture-play.

THE SWITCH-BOARD OF A MODERN PICTURE-PLAY STUDIO

This control is in one of the studios of the Broadwest Film Company, Limited. The switch-board is divided into left, right and overhead lighting sections respectively In the foreground may be seen the arc now used for flood-lighting, and the "spot-light," a miniature low-powered searchlight, devised for kinematograph service.

THE HYDRO-ELECTRIC ENGINEER'S WRESTLE WITH THE NIAGARA RAPIDS.
To reclaim 12 acres from the river-bed on which to erect the power-house, a coffer-dam 2,200 feet long, had to be built. Owing to the velocity of the water—22 feet per second—and its depth, which ranged from 8 to 24 feet, massive timber baulks were necessary.

The Taming of the Niagara Falls—I

TRAPPING NATURE'S SPECTACULAR WASTE TO INAUGURATE INDUSTRIES OF STRIKING MAGNITUDE AND ECONOMIC IMPORTANCE

FROM the day when the hardy pioneers, lured by Father Hennepin's impressive pen picture, flocked to the primeval forest fringing that "vast and prodigious cadence of water," the practicability of transforming the Niagara Falls into a weapon of industry has exercised an irresistible fascination. Apparently, the first effort in this direction was made in 1725 by a settler, who, being of a mechanical turn of mind, and fully alive to the advantage of labour-saving machinery, impressed the water to drive the wheel coupled to his sawmill.

The water tumbling over the lofty precipice on its way from Lake Erie to Lake Ontario still drives water-wheels, but of a vastly different character and under supremely changed conditions. The transformation came when the diligent workers of Europe demonstrated to the world the possibility of converting hydraulic energy into electricity.

The ambition to tame that mighty tumble of water was laudable and logical. The Niagara River is only 33 miles in length, but in that distance it drops 326 feet, the greater part of the descent occurring through the last 17 miles. It drains an area of 90,000 square miles, and has a total flow ranging from about 215,000 to 275,000 cubic feet per second. However, the factors of decisive moment to the hydro-electric engineer, are the constancy or regularity of its flow, and its immunity from the adverse influences generally incidental to waterways contemplated for such exploitation. It is not affected by rainfall, snow-fall or temperatures. Such variations as occur are wholly due to the wind. If this be blowing strongly from the East across Lake Erie, it drives back and holds up the water, but if the wind be raging from the opposite direction it hurries the water along.

Physically the waterway is eminently adapted to such a conquest. About a mile above the spectacular plunge the river becomes comparatively constricted; the huge volume of water is forced through a channel having a maximum width of 4,750 feet, and forms the Upper Rapids. There, owing to the drop of 52 feet, the river seethes and boils, while its current runs viciously. But its free passage is disputed by the straggling projection—Goat Island—which splits the river unequally in twain. The stream swinging round the southern side of the island is precipitated over a ledge 1,060 feet in length by 167 feet in height—the American Fall. The water which sweeps round the northern side of the island hurtles over a cliff 3,010 feet in length by 158 feet in height—the Horseshoe or Canadian Fall.

Niagara's Spectacular Plunge

The unequal subdivision of the river causes about seven-eighths of the total volume of water to rush over the Horseshoe ledge, the average depth of water on the crest of which is 20 feet, as compared with 8 feet for the American Fall. Yet there is ample power for both countries. According to calculations the total drop in the water, from the commencement of the Upper Rapids to the cauldron immediately below the Falls, is 216 feet, and adequate to furnish a theoretical aggregate of 6,750,000 horse-power. If the additional drop of 100 feet occurring during the succeeding 8 miles to Lewiston be taken into consideration, giving a total descent of 316 feet, then the theoretical total becomes swelled to 10,000,000 horse-power. But desiring to be conservative in his computations, the engineer accepts the available hydraulic energy at 5,500,000 horse-power.

The First Electric Scheme

The initial practical demonstration of the commercial potentialities of the hydraulic energy of the Niagara Falls in the electrical sense was made upon the Canadian shore. In 1888 the Commissioners of Niagara Falls Park invited proposals for the construction and operation of an electric scenic railway from Queenston to Chippewa. The proposal was animated by the desire to afford to tourists the opportunity of enjoying the wonders and beauties of this spectacle without being exposed to the extortionate demands of the cabmen who, until Lord Dufferin's spirited protest, rendered the existence of pilgrims to the Falls intolerable. Incidentally the railway would prove a source of revenue to the park.

It was not until 1892 that a group of enterprising Canadians decided to take advantage of the offer. They formed the Niagara Falls Park and River Railway, now known as the International Railway Company, and secured the concession for an annual rental of £2,000. The railway was speedily completed, and the necessary energy was drawn from a power-station planted near the head of the Horseshoe Fall. This building was equipped with one 2,000-horse-power turbine and two

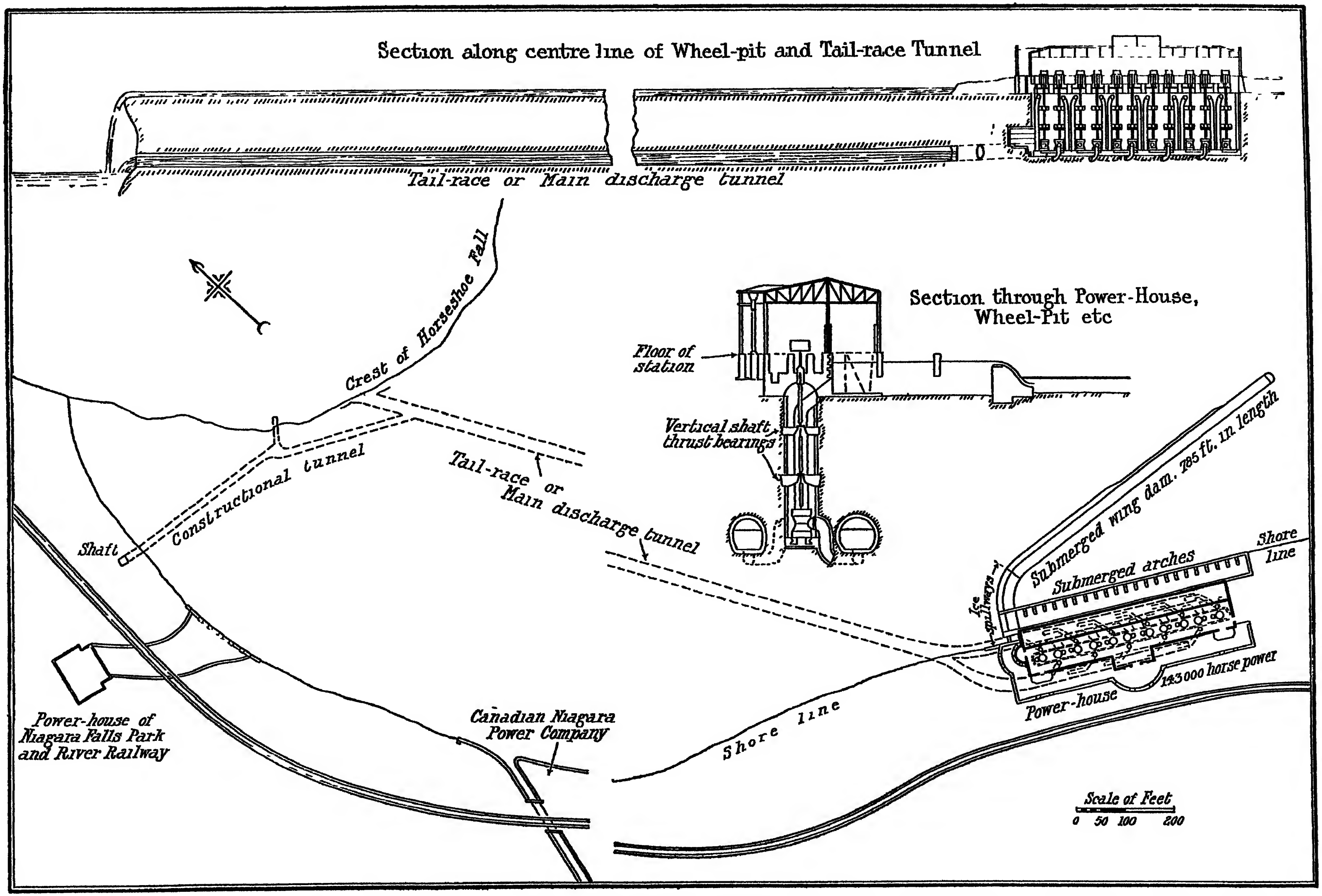
1,000-horse-power turbines—4,000 horse-power in all, operated under an average head of 65 feet, which drove one 1,500-kilowatt and five 200-kilowatt generators—total output 2,500 kilowatts. While the greater part of this energy is absorbed by the railway a small quantity is distributed for general lighting and power purposes.

But the first decisive assault upon the 30,000,000 tons of water falling over Niagara's lofty ledge every hour was delivered by the hydro-electric engineer from the American side. In 1853 was launched the Niagara Falls Hydraulic Power and Manufacturing Company, to tap the river above the cataract, and to lead the water through a canal for the generation of hydraulic energy. Of course, at that date there was no idea of converting the potential power into electricity, because the possibility of utilizing water to secure that form of energy had not even been mooted.

For the execution of this hydraulic scheme, an open canal, 4,400 feet in length, was dug from the upper river and conducted through the town to a point about a mile below the Falls. At the intake this artificial waterway was 250 feet wide by 14 feet deep, but in the course of 400 feet the width was reduced to 100 feet for about 1,000 feet, when there was a further reduction to 70 feet which was maintained for the remainder of the distance, while the depth was likewise reduced to 8 feet. This canal discharged into a basin about 400 feet long by 70 feet wide, set about 300 feet back from the brink of the gorge.

THE DRY FOREBAY AND COMPLETED WING-DAM INSIDE THE COFFER-DAM

The wing-dam—built to increase the natural water-level at the penstock inlets of the Electrical Development Co.'s power-house—is 785 feet in length, has a maximum height of 27 feet, and projects into the river at an angle. The Rapids now roll over this barrier to a depth of 10 feet.



DIAGRAMMATIC PLAN OF THE HARNESSING OF THE NIAGARA RAPIDS BY THE ELECTRICAL DEVELOPMENT COMPANY.

Copyright photo L. L. and P. N. Nunn

HOW CANADA IS WRESTING 494,000 HORSE-POWER FROM THE FALLS OF NIAGARA.

The famous Cataract, representing 5,500,000 horse-power, as seen from the air. Immediately below the Fall the Ontario Power Company generates 238,000 horse-power; above the Fall the International Railway Company, 4,000 horse-power, the Canadian Niagara Power Company, 109,000 horse-power; and the Electrical Development Company, 143,000 horse-power. The Hydro-Electric Power Commission controls the first and last-named undertakings.

When the possibility of generating electricity from water-power was conclusively demonstrated, it was decided to convert the original purely hydraulic power into an electrical scheme. A station was built at the base of the cliff, directly under the receiving basin or forebay, and disposed in such a manner as to give a static head of 216 feet. The first power-station was completed in 1896, and the water was delivered thereto from the forebay above through a steel penstock, 8 feet in diameter, to drive four 2,250-horse-power water turbines coupled to eight generators. This initial equipment proved so satisfactory, and its output was so promptly absorbed, as to lead to the immediate extension of the installation. This involved the building of a second penstock, 13 feet in diameter, projecting horizontally from the forebay at the top of the cliff for a distance of 60 feet, when it descends vertically. This penstock has a capacity of 12,500 horse-power, and drives five turbines ranging from 2,300 to 3,000 horse-power each. To ensure a sufficient water-supply the canal was widened to a uniform 100 feet, and deepened to 14 feet; the output of the station thereby was increased to 32,500 horse-power.

While the foregoing scheme was being carried out, the Niagara Falls Power Company inaugurated another undertaking, which followed quite a different method, to convert the available hydraulic power into electricity. It established its power-station above the Falls, leading sufficient water to develop 100,000 horse-power through a canal 1,700 feet long by 250 feet wide and 12 feet deep to the power-house. The proposal was to build two 50,000-horse-power stations, one on each side of this canal, but at first only one unit was taken in hand. At the inner end of the canal a huge rectangular pit, measuring 330 feet long by 20 feet wide, was excavated to a depth of 178 feet, to receive the water-wheels. Ten 5,000-horse-power turbines, designed by Faesh and Piccard, of Geneva, but built by the I. P. Morris Company, of Philadelphia, were set in the bottom of this pit; the water was led thereto from the canal above through eight steel penstocks, measuring nearly 8 feet in diameter, and delivered the water under a head of 136 feet.

Big Power Schemes

The turbines might be described as two such units placed one on top of the other with the upper inverted, so that the circle of buckets became resolved into three layers. This combination was enclosed in a kind of drum-shaped casting. The penstock was connected to the latter at a central point, with the result that one-half of the inrushing water, rising in the drum, played upon the topmost ring of buckets, while the second half actuated the lower wheel. By this arrangement the upward pressure, due to the static head of 136 feet, served to carry a variable proportion of the weight of the huge shaft which extended vertically from the turbine to the generator set upon the floor of the power-house above.

Giant Turbines

The discharge of the water from the turbines was overcome by driving a tunnel, at a gentle slope, for a distance of 7,000 feet from the bottom of the wheel-pit back to the river a short distance below the Falls. When running under conditions of full load the wheels discharged 430 cubic feet of water per second; the speed of the turbine was 250 revolutions per minute and developed 5,000 horse-power.

The shaft upon which both the turbine and generator were mounted comprised for the greater part of its length a steel tube, 38 inches in diameter, and having a wall $\frac{3}{8}$ inch in thickness. At the upper end this tube gave way to a solid steel shaft 11 inches in diameter, to carry the revolving field of the generator. Owing to the length of these shafts steadying bearings, supported upon massive steel girders, had to be introduced at regular intervals. A continuous

flow of oil had to be passed through the journals to ensure efficient lubrication; while the bearings had to be kept cool by a water circulation. Constant readings of the temperature of the oil, after it had passed through the journals, were taken to guard against over-heating. Provision was also made to shut off the water-flow to any of the turbines when required; and a friction brake was fitted to the steel shaft to bring the turbine to rest.

EXCAVATING THE WHEEL-PIT.

A chasm 416 feet long by 22 feet wide was blasted out of the solid rock to a depth of 150 feet. The pit is spanned at three levels by flying arches carrying the bearings of the vertical turbine shafts, upon which the generators at the surface are mounted. The water makes a vertical plunge of 140 feet through steel penstocks, 10½ feet in diameter, to the 11 turbines installed at the bottom.

The stationary armature of the generator was carried upon a heavy casting bolted to the arched top of the wheel-pit, level with the power-house floor. The rotating-field ring carried on its interior face twelve field-poles, each of which, with its winding, weighed 2,800 lb. The total weight of each generator was 85 tons, of which the revolving field represented 45 tons. The two-phase 2,000-volt current was led from each generator to a special switch-board operated by compressed air, and was finally passed through a special covered passage across the canal to a small building on the opposite bank housing the trans formers, where the greater part of the current was stepped-down to meet the requirements of the local consumers.

When the attack upon Niagara's power was grimly taken in hand, imaginative writers depicted villages, towns and cities within a radius of 100 miles without smoke; coal and other fuels would be eschewed for electricity. The City of Buffalo, 26 miles away, expressed its readiness to absorb 6,000 horse-power the moment it became available. For this purpose the current was stepped-up from the generator pressure of 2,200-volts two-phase, to 11,000-volts three-phase, and conveyed thither by overhead transmission.

Success was immediate; the Niagara power-stations became the talk of the whole world. Both companies secured immense tracts of land contiguous to their plants;

established and new industries, to which electricity is absolutely indispensable, alike grasped the opportunity to secure cheap power. Among these industries may be mentioned the manufacture of calcium carbide and calcium cyanamide, carborundum, metallic sodium, phosphorus and alkalis. In this way a heavy sustained demand speedily became imposed upon the available fount of electric energy, and brought about the prompt installation of the second unit of 50,000 horse-power, which was also quickly absorbed. Since then development has been steadily maintained.

Rush for Rights

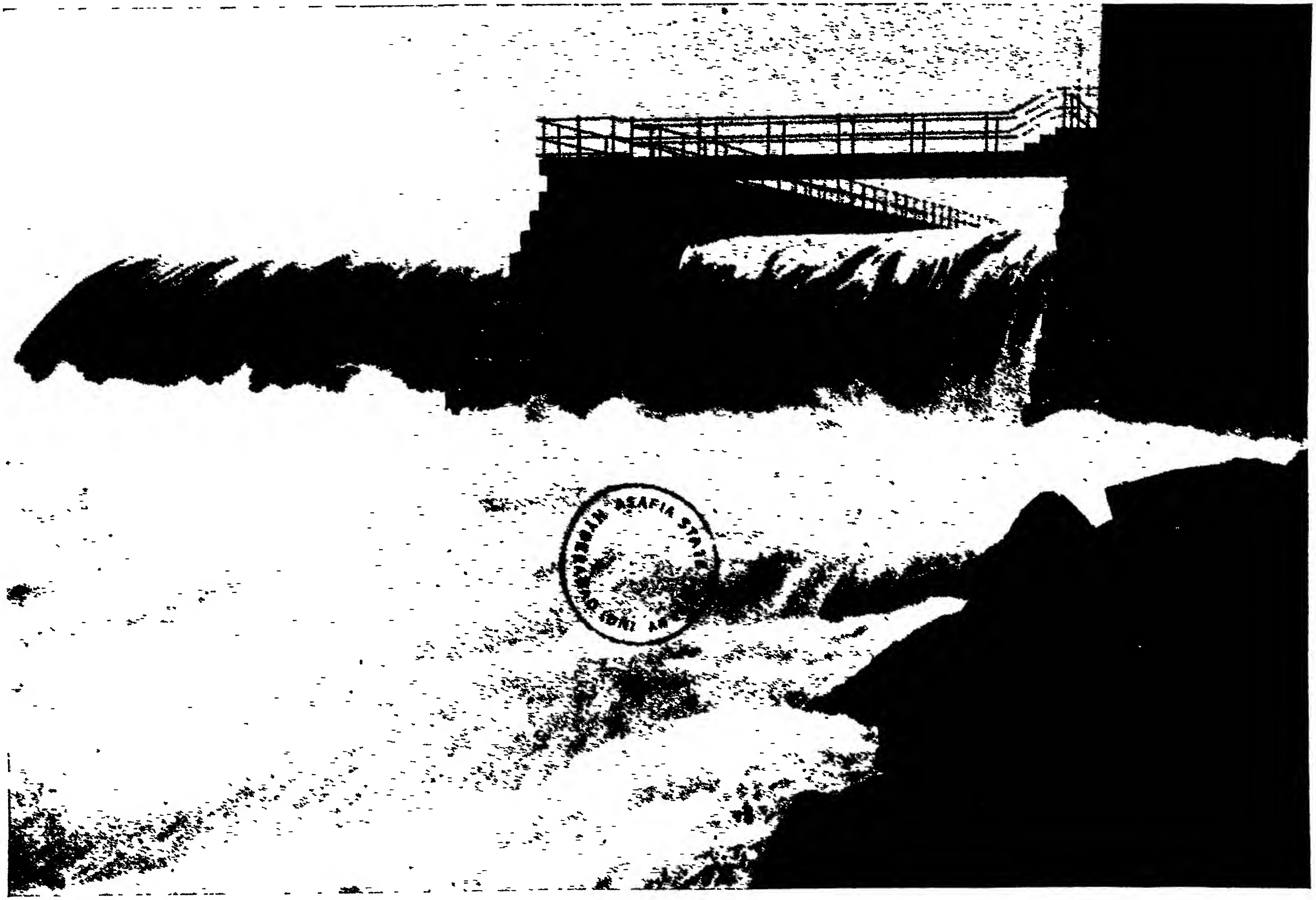
A stampede for rights to Niagara's hydraulic energy for the generation of electricity followed these initial successes. The financial-engineering onslaught was not confined to the American shore, although American capitalistic interests were most active in this field. The fact that seven-eighths of the total volume of water poured over the Horseshoe Fall, led to the Canadian bank being coveted. The Niagara Falls Power Company succeeded in securing the necessary powers to establish a station of 250,000 horse-power capacity upon the Canadian bank to generate the current in Canada and export it to American consumers.

In the course of a few years this company exercised its rights in this connexion by forming the Canadian Niagara Power Company, and selected a site for the proposed plant in Queen Victoria Niagara Falls Park. Generating rights for a period of fifty years, with option of renewal by ten-year periods up to 110 years in all, were secured, together with title to sufficient water to generate 100,000 horse-power, at a total rental of £3,000 a year up to 1949, with an additional payment upon a sliding scale, ranging from 4s. to 2s. per horse-power per annum. Only one stipulation was made by the Canadian authorities—20,000 horse-power was to be ready by 1904; but by that date the company was able to deliver 50,000 horse-power.

The method favoured by the company in question upon the American bank was followed. The water is drawn from the Niagara River about 500 feet above the Horseshoe Fall, and led through a canal to the wheel-pit. Since the first unit was brought into operation successive extensions have been carried out; the plant now in operation comprises five 10,250 horse-power turbines, three of 10,750 horse-power, and two of 12,750 horse-power—total delivery 109,000 horse-power. The electrical generating equipment comprises five three-phase 25-cycle 7,500-kilowatt, and five three-phase 25-cycle 10,400-kilowatt units —89,500 kilowatts all told. By the time the designed extensions are completed the total turbine capacity of the station will be 128,000 horse-power. The current thus generated is not only distributed locally, but is sold in large blocks to the parent company upon the American bank, and also to the company established in the City of Buffalo for the distribution of electricity for all purposes.

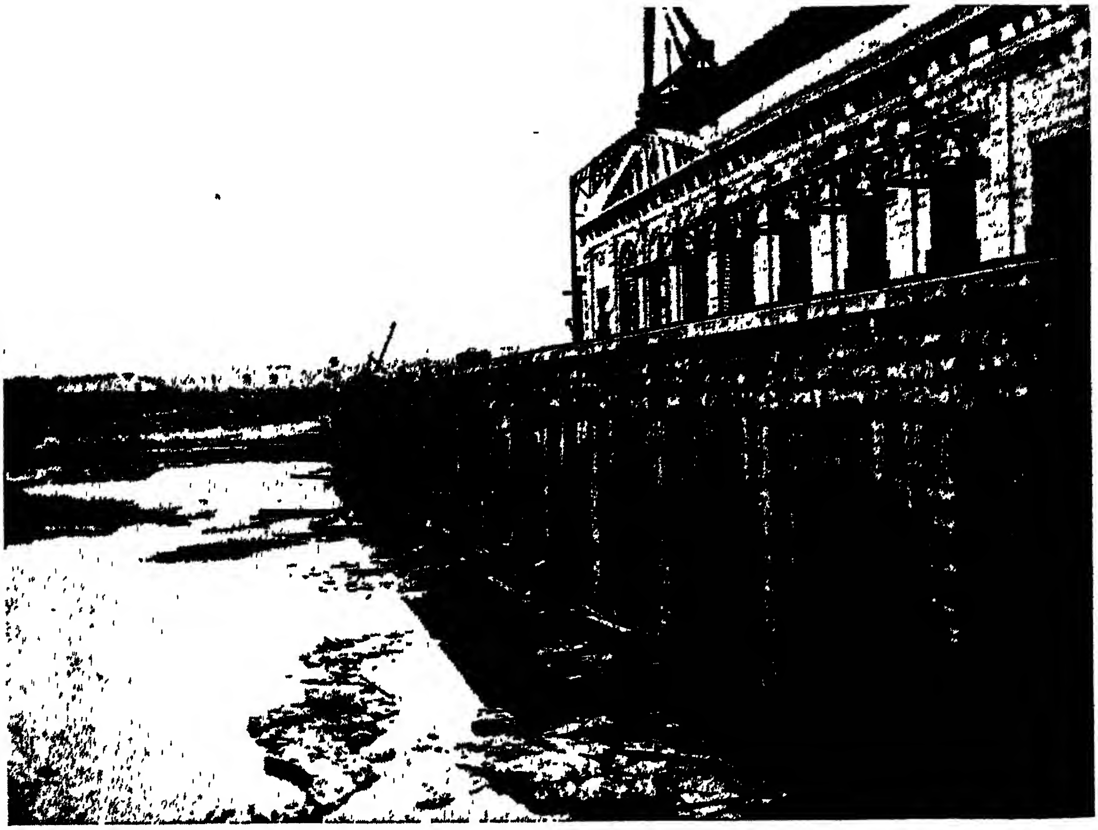
Inter-continental Competition

Another group of American capitalists also succeeded in acquiring the concession to exploit Niagara's power on the Canadian shore. This was the Ontario Power Company, which also selected a site for its station in the Queen Victoria Niagara Falls Park, but below the cataract; the installation was set at the bottom of the cliff, a few feet above the water's edge. Constructional operations were commenced in July, 1902. The water is drawn from the river at the first cascade of the Upper Rapids, but, instead of the water being conveyed by an open canal as upon the opposite shore, it is led through two conduits to the power-house. These conduits are somewhat notable. They are each 6,600 feet in length by 18 feet in diameter, and buried in a trench; whereas the first built in 1903 is of steel, embedded



A MINIATURE NIAGARA AT THE POWER-HOUSE OF THE ELECTRICAL DEVELOPMENT COMPANY.

The Rapids pouring over the submerged wing-dam and spillway. This submerged barrier sets up an outwardly sweeping current to swing floating ice and rubbish from the guard-racks over the entrances to the penstocks.



DRAINED FOREBAY, SHOWING OUTER LINE OF ARCHES IN THE ELECTRICAL DEVELOPMENT COMPANY'S SCHEME.

The Rapids now roll through this space to flow through the arches to the penstocks. Behind the parapet of the arches is seen the river façade of the power-house.

in concrete, the second is of reinforced concrete. Each of these two conveyers terminates in a surge tank, the second and more modern of which is able to act as a regulator for the plant as a whole.

The water is distributed from these two main conductors through steel penstocks, each 9 feet in diameter. The first conduit supplies six and the second conduit eight of these penstocks, which are built in tunnels driven for about 300 feet through the solid rock. The head of water thus obtained is 180 feet, and the fourteen penstocks furnish hydraulic energy to an equal number of turbines, rated at 189,000 horse-power. One half of the turbine installation comprises units each of 11,800 horse-power running at 187·5 revolutions per minute. Of the other seven, five are each rated at 15,000 horse-power, and two each at 16,000 horse-power. Later additions increased the capacity of the station to 238,000 horse-power. The turbines are coupled to alternating current three-phase 25-cycle generators.

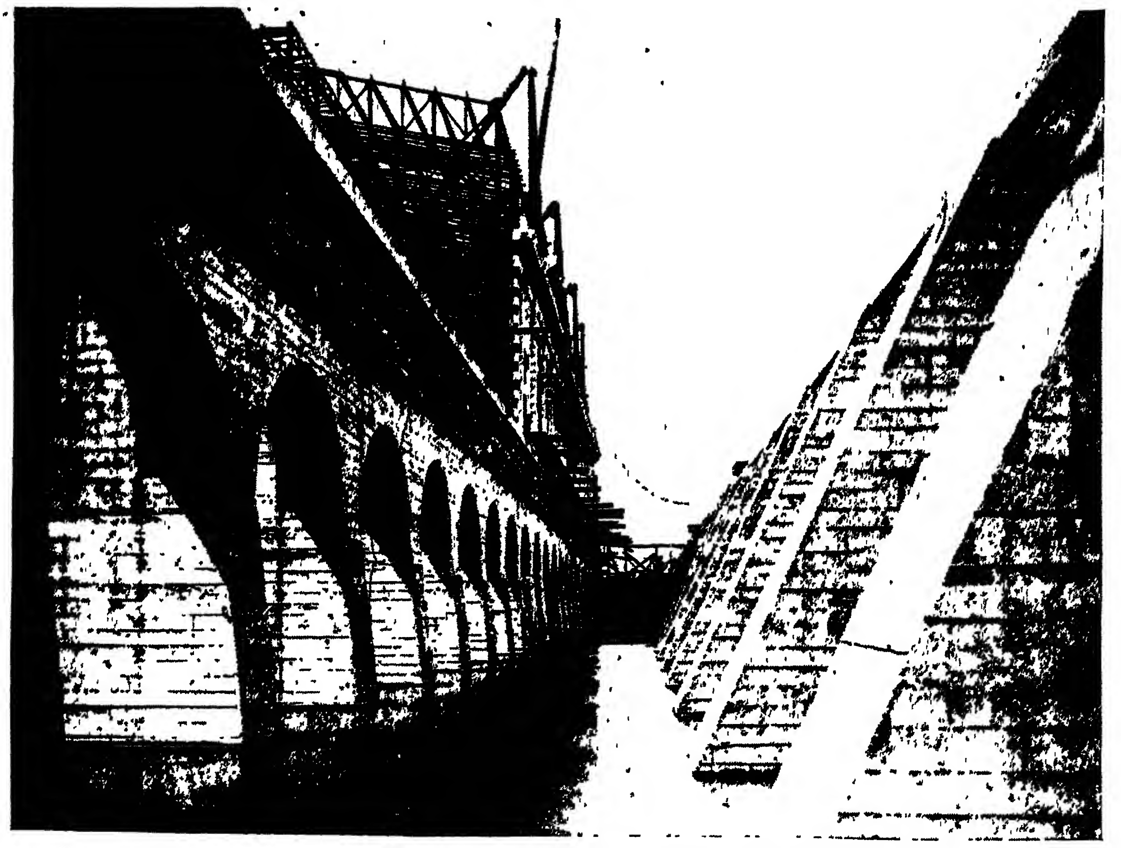
As the main mechanical features of this installation are of impressive dimensions, it is only logical to find immensity extended to the minor yet indispensable adjuncts of the plant. A detail of this character is the electric valve controlling the flow of water to each penstock. This huge valve, which is of sufficient diameter to allow the easy passage of a motor-car carrying five passengers, was designed and built at Indian Orchard, Massachusetts. It has an overall height of 30 feet, by 11 feet in width, and measures 7 feet in thickness over the flanges; the opening is 9 feet in diameter. Complete it weighs 65 tons. The body of the valve is of cast-iron; while the gate, of

cast-steel weighing 9 tons, is able to resist a pressure of 60 lb. per square inch, or a total load exceeding 500,000 lb. To relieve the pressure encountered when opening or closing the valve there is a 14-inch by-pass valve.

The valve is electrically operated, through gearing; a 15-horse-power motor is reserved for this duty. The two spindles which actuate the gate are each over 12 feet in length. The motor cannot be started in the wrong direction because of the automatic switches introduced at the top and bottom of the gate travel; there is also an interesting magnetic brake to stop the valve instantly. When the gate is partly open the motor may be started as required; but if the gate be wide open the motor can only be restarted in the direction to lower the gate, and vice versa. The time occupied in fully opening or closing the valve is three minutes.

This plant, financed by American capitalists, was undertaken essentially to generate power for export in bulk to the supply and distribution companies entrenched upon the American bank, and to extend the radius or zone which it was decided to electrify. The first three units were brought into operation in July, 1905, and five months later, the transmission system having been completed, power was delivered to Lockport, and a year later to Syracuse in the State of New York, a distance of about 60 miles.

The development of Niagara's power upon the Canadian side by two large stations prompted the formation of a third



LOOKING BETWEEN THE INNER AND OUTER ROWS OF THE ARCHES OF THE FOREBAY BEFORE SUBMERGENCE.

When the subaqeous work was completed, the coffer-dam was demolished to allow the water to resume its natural flow and level to within about 5 feet of the parapet.

undertaking. Unlike its predecessors, this enterprise was essentially Anglo-Canadian. Sir William Mackenzie, who had been identified with the Canadian Northern Transcontinental Railway and its subsidiaries, as well as the supply of electric energy for the cities of Winnipeg, Victoria and Vancouver, was one of the prime movers. The power developed was to be used wholly for the lighting and tramways service of the City of Toronto. Thus the Electrical Development Company, controlled by the Toronto Power Company, was formed in 1903 with a capital of £1,200,000, and was accorded the right to draw upon the source of supply to the extent of 125,000 horse-power upon terms similar to those made with the previous undertakings.

Third Niagara Scheme

This third Niagara harnessing scheme upon the Canadian bank is undoubtedly the most remarkable. The engineering features were prepared by Mr. Hugh Cooper, who subsequently conceived the scheme for taming the Mississippi River, and who had been responsible for another daring project at Falls Ferry, Susquehanna, in the State of Pennsylvania.

This engineer likewise selected a site in the Canadian Park at Niagara Falls for his power-house, a short distance above the Horseshoe Fall; but, in order to reduce the encroachment upon public property to the minimum, he decided to wrest a portion of the bed of the Rapids upon which to erect the necessary buildings. This was indeed a bold proposal; to essay to reclaim 12 acres at a point where the torrent was swinging madly along at 22 feet per second, and where the water ranged from 8 to 24 feet in depth seemed to be tempting the fates with a vengeance. Considered in the paper aspect this scheme appeared to be only possible of fulfilment at prodigious cost.

To effect reclamation it was necessary to build a huge coffer-dam to resist the fearful pounding of the torrent. Work was commenced on April 2nd, 1903, and foot by foot the crib work was pushed forward into the river. Massive baulks of timber had to be swung out and deftly guided into position by men equipped with "pe-vees," and who often were forced to assume hazardous foothold amid the spray and foam to carry out their task. The water poured through and over the skeleton framework of wood with the savagery of a titanic mill-race. Now and again a massive baulk of timber would be whisked towards the Falls as if it were a straw. In a year's time the coffer-dam was pushed to a length of 2,200 feet, enclosing land over which the river had hitherto held undisputed sway.

Solid Foundations

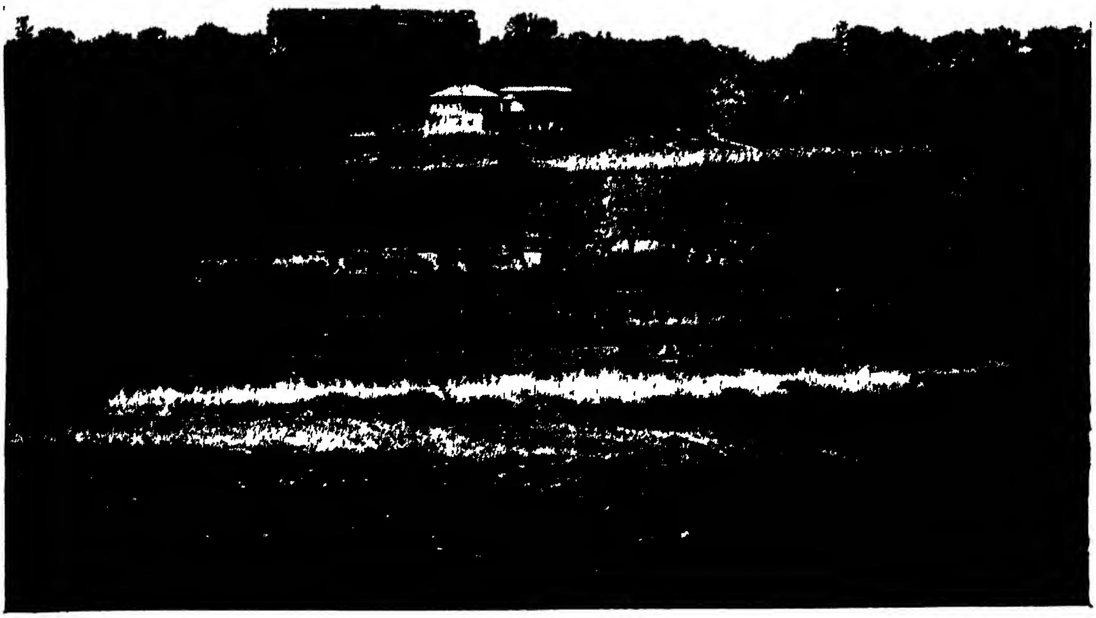
The twelve acres thus recovered were designed to form the forebay, to receive the wing-dam, the wheel-pit, and the major part of the superstructure forming the power-house. A more solid foundation could not have been desired. Geologists found the bed to be dotted with rock as hard as granite, but worn by the forces of attrition into the most fantastic shapes. It put up a stern resistance to the chugging of the drills, and the rending forces of explosives.

The tract of dry river-bed afforded full scope for the other phases of the essential development work. The concrete wing-dam, 27 feet in height and crowned with granite, creeps out into the river for a distance of 785 feet. It was built to increase the natural water-level at the penstock inlets, and to set up an outwardly swinging current from the guard-racks, to prevent ice gathering around the inlets, and thus impeding the natural flow of the water to the turbines.

On the drained foreshore, parallel to the river, was built a double row of lofty arches, set some distance apart, leaving a long narrow lane between. The water passes through the openings of the outer wall freely; within is a line of racks, carried by inner buttresses, to prevent the intrusion

of flotsam and jetsam as well as submerged ice to the turbines. At the north end of this lane is a spillway, which also serves as an outlet for such submerged ice as may succeed in forcing its way by the wing-dam tical steel shafts, which couple the turbines at the bottom of the pit with the generators on the floor of the power-house overhead.

The water, led through vertical penstocks to the wheels at the bottom of the



THE HYDRO-ELECTRIC STATION OF THE ONTARIO POWER COMPANY BELOW THE FALLS.
The power-house is built at the foot of the cliff by the water's edge. On the top of the cliff, on the right, may be seen the surge tank; in the centre, at the back, is the transformer building, whence the current is stepped-up to 110,000 volts for transmission to all parts of south-western Ontario. This photograph, taken from Goat Island, shows the water emptying into the river after passing through the turbines.

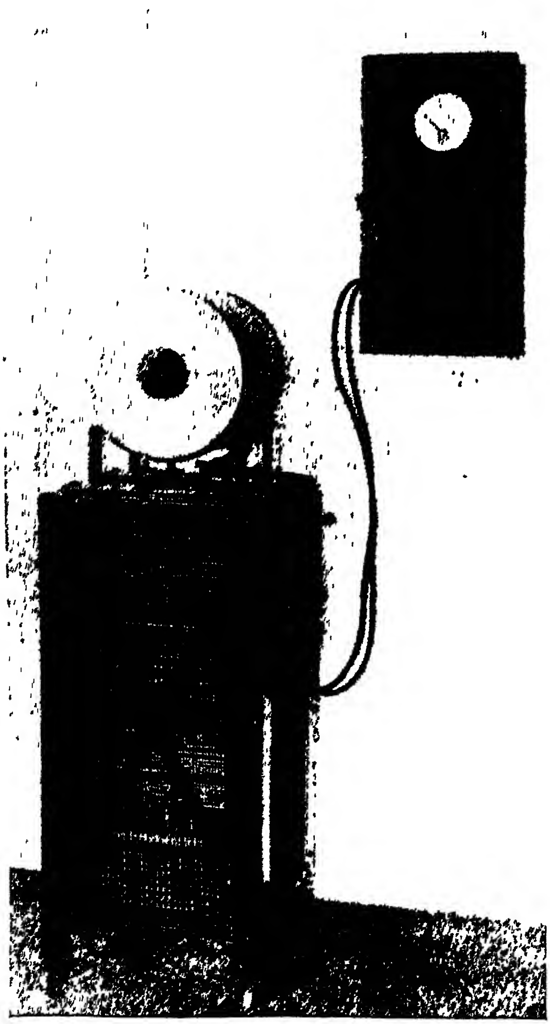
and through the arches. These arches support the river façade of the power-house above; the greater part of the work is thus erected upon reclaimed land in accordance with the original designs.

Behind the arches, the wheel-pit was sunk into the solid rock. It is a huge rectangular chasm, 416 feet long by 22 feet wide and 150 feet deep. From top to bottom on all sides, it is lined with brick. At the lower level are the supports for the turbines; while at three different levels the rift is spanned by eleven flying arches to carry the bearings of the ponderous ver- pit, is divided into two currents, so as to enter the turbine from above and beneath. In this way the upward thrust exerted is exactly calculated to carry the weight of the enormous parts, so that the turbine and its vertical shaft practically float in the water which drives them. In addition there is a massive vertical bearing for each turbine carried on the flying arches bridging the wheel-pit, and lubricated by oil under a pressure of 350 lb. per square inch. This is adequate to support the weight of the whole of the revolving mass should the water thrust fail.

The Magnet in Surgery

HOW PAINLESS EXTRACTION OF IRON AND STEEL SPLINTERS FROM THE EYES AND SKIN IS ACCOMPLISHED

DURING the past few years the employment of the magnet as a surgical instrument has developed somewhat extensively. Working in iron and steel is attended by many disabilities which the mechanic is apt to regard lightly, if not with absolute indifference. Minute particles and tiny splinters of metal removed by the tool are constantly flying in all directions, many seeking refuge in the skin, while now and again a fragment lodges in the eye. Skin penetration may possibly escape observation owing to the calloused character of the metal-workers' hands, but when the eye is assailed the presence of the foreign particle speedily asserts itself. It is imperative that the injury should receive prompt and efficient attention. To attempt to seek relief in the usual primitive manner is likely to aggravate the injury and cause the metal splinter to become more deeply embedded.



THE SURGICAL MAGNET

The instrument is mounted horizontally upon the top of a cabinet which carries the resisters. The intensity of the current is controlled by the handle at the side.

The circumstance that iron and steel, being magnetic, will respond to the pull exerted by a magnet, prompted the application of this familiar toy to such duty. Obviously, the instrument must be designed along correct lines to ensure the operation being performed efficiently, while the attractive effort must also be adequate to extract the metallic particle from its position. It was the frequency with which pieces of iron and steel lodge in the eyes of the workers, and the difficulty experienced in their removal, which first suggested the employment of the magnet in this capacity.

In the course of brief experience, it was discovered that the most successful and speediest results were achieved by utilizing the magnet in a fixed horizontal position and by varying the form of the working-pole. It was found that a working-pole point, which promptly removed a piece of steel floating loosely in the eye, was not

necessarily equally applicable to the extraction of a splinter which had become firmly embedded. It was also necessary to provide the pole with such a form as would permit the oculist to observe and follow the operation, as well as to enable him, after once having discovered the position of the foreign body and brought it under the influence of the magnet, to draw it clear of the eye.

During the war the employment of the magnet in the surgical capacity was freely favoured by the hospitals for the removal of pieces of shrapnel from flesh wounds. The recourse to explosives of the very highest character brought about the more complete fragmentation of the shell; some of the pieces which were buried in the body, and to an appreciable depth, were no more formidable than a bramble thorn, but, at the same time, these set up excruciating pain and were liable to precipitate poisoning. The employment of the magnet in such work was appreciably facilitated by the experience which had attended its use in certain industrial factories, where steel splinters are responsible for a high percentage of casualties which, if neglected, are apt to develop into serious and costly misadventures.

For some years past the Westinghouse Electric and Manufacturing Company has reposed dependence upon the magnet for the treatment of the superficial injuries of its employees caused by flying particles of steel. This ingenious first aid is installed in the Relief Department, or accident ward, of its East Pittsburg works.

The magnet is mounted upon a box which carries the resistance for the regulation of the volume of current flowing through the coils to the pole-piece. The magnet is set up in such a manner as to bring the pole-piece to the horizontal position, and at a height convenient for the treatment of wounds in any part of the body. By mounting the instrument upon wheels it is possible to move the magnet through the horizontal plane, and at the same time derive all the advantages arising from a fixed position. It may be explained that, in some instances, the practice of swinging the magnet is followed, but this is not

EXTRACTING A STEEL SPLINTER FROM THE EYE
Showing short pole of magnet used for the removal of loose particles.

generally endorsed, because while it may possibly allow the magnet to be held at any angle, it is difficult to hold it steady. The magnet is very powerful; 4,000 watts, or sufficient power to light one hundred 32-candle-power Mazda lamps, are demanded for its operation. It is designed for use with a pressure of 70 volts, and as the circuit from which current is drawn for its manipulation is that installed for testing purposes in the works, and the potential of which varies from 70 to 120 volts, the introduction of the resistance is necessary.

The manipulation of the magnet is very simple. Upon the surgeon being informed of the approximate situation of the splinter, the working-pole, having the most efficient

form for the seat of injury and the attraction of the particle, is screwed into place, and the affected part brought to the pole-point. The surgeon then switches on the current, and gradually increases it by moving forward the rheostat, a notch at a time, until at last, the necessary attractive effort being imparted, the splinter is slowly withdrawn to cling to the pole-point of the magnet. In the case of a flesh wound, say, the penetration of the forearm or hand by a splinter, the pole-piece used is generally slightly elongated and curved, so as to bring the pole-point in line with the splinter and thus withdraw it in the direction opposite to that which it followed when penetrating the skin. At the same time the surgeon is enabled to follow the operation and to satisfy himself that the magnetic flux is being properly directed.

At the Pittsburg works this magnet has proved to be a highly profitable apparatus. The workman, directly he realizes that a particle of steel has flown into his eye, proceeds to the surgery. He is not permitted to neglect the accident on the plea that it is trivial. Prompt attention guards against the possibility of the splinter becoming more deeply embedded through repeated rubbing of the irritated organ by the hand. When the current is applied, the particle is almost instantaneously withdrawn, even if it be deeply embedded, and without the slightest pain to the sufferer. The removal of such a particle before the installation of the magnet was invariably a difficult, as well as a painful, undertaking. The protective coating of the eye often had to be cut, while there was the risk that, instead of removing the particle, it was pushed farther into the eye during the process. Once the foreign body reached the eyeball the aid of

REMOVING AN OBSTINATE PARTICLE OF STEEL FROM THE EYE.
Should the piece of metal be embedded, its extraction is a delicate operation which demands the use of a long tapered pole to effect clean complete withdrawal.

a specialist was imperative. Under these conditions often the most trivial mishap was attended with serious developments, demanding the man's absence from his duties until recovery was complete. By bringing the magnet to bear upon the splinter promptly the mechanic's withdrawal from service is reduced to a few minutes, and without more than passing interference with the normal working of his eye.

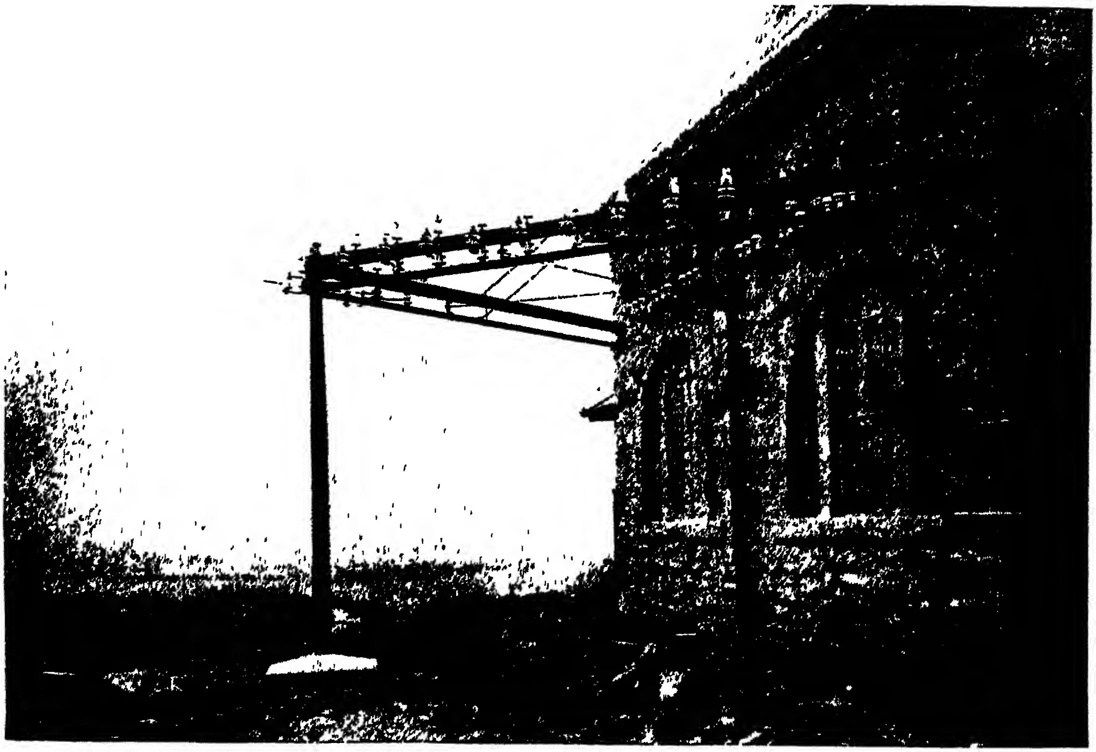
It is the hands which suffer most severely from steel splinters. These minute fragments penetrate the callouses and secure a firm refuge beneath. Unless these splinters are promptly removed the wound is likely to become septic. The difficulty is that the workman probably does not realize that he has received a splinter until inflammation with attendant pain develops. Formerly such splinters demanded discovery and removal by probing, or the use of pincers and needles, a practice which was not only uncertain, but tedious, and attended by considerable pain. But with the magnet a calloused hand, riddled with splinters, may be cleared of every trace of such particles promptly and painlessly. The medical director to the Westinghouse staff extracted one less than the twelfth of the thickness of a delicate needle.

This surgeon, Dr. C. A. Lauffer, relates innumerable instances of the invaluable work accomplished by the aid of this appliance. One is somewhat amusing. A workman, afflicted with toothache, suddenly conceived the idea of becoming his own dentist and essayed to stop the offending molar. For this purpose he fashioned a very fine tool and therewith set out to drill his tooth. To his dismay the drill suddenly snapped about half an inch from the end. The *dénouement* was somewhat disconcerting, because the broken piece remained firmly embedded in the cavity and

HOW STEEL SPLINTERS ARE REMOVED FROM THE SKIN BY THE SURGICAL MAGNET.

For this work another form of pole, having a thin bent point, is necessary.

resisted every effort to bring about its removal. As the man was seriously inconvenienced by the projecting half an inch of steel, it appeared as if he were destined to lose his tooth. In his dilemma he sought the counsel of Dr. Lauffer. The medical director designed a special extension for his surgical magnet. This was speedily made and the drill stump brought into contact with it. The current was switched on, and, within a few seconds, the broken drill end was withdrawn.



THE STARTING POINT OF THE "TRANSMISSION" AT THE SNOWDON STATION OF THE NORTH WALES POWER AND TRACTION COMPANY.

The outgoing feeders are brought from the high-tension switch-gear to this straining frame outside the power-house.

Triumphs of Transmission—II

NORTH WALES AND THE PACIFIC COAST

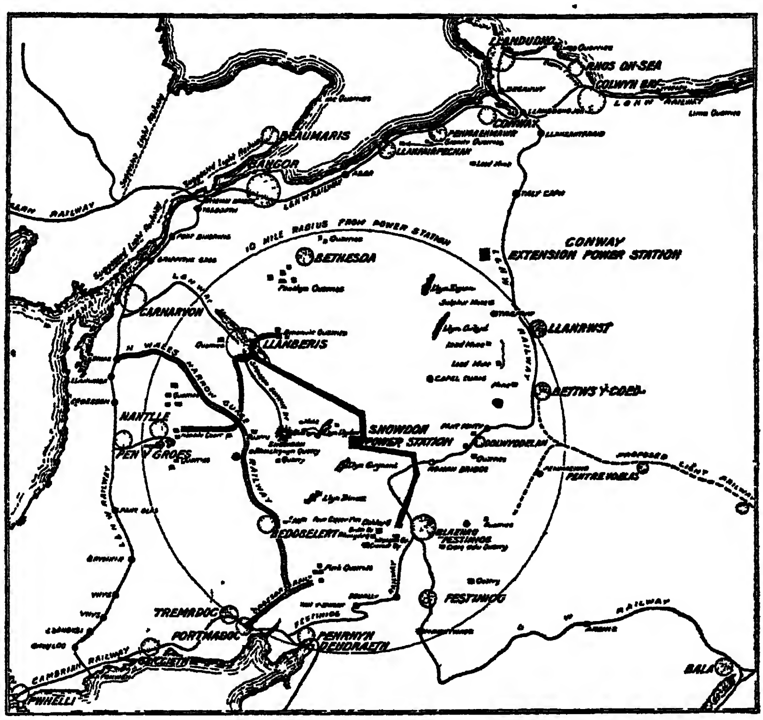
SO far as Great Britain is concerned long-distance transmission of high-tension electricity is practically unknown. Although we have a hydro-electric station in Scotland developing 35,000 horse-power, the energy is used upon the spot. In many of our industrial areas there are impressive plants where power is generated by steam, blast-furnace and other gases, waste-heat, and oil, but their distribution systems for the most part belong to quite a different order. The most notable installation is that of the North Wales Power and Traction Company, which distributes the current derived from the harnessing of the waters of Llyn Llydaw, Snowdon, throughout a radius of 10 miles from the power-station.

Doubtless the stranger, bent on viewing the natural beauties of North Wales and whose footsteps have taken him by way of the Llanberis Pass into the rugged fastnesses of the Principality, has had his attention arrested by a network of wires spanning the road. Possibly he has failed to give them a second thought, dismissing them as telegraph or telephone wires. But close observation reveals that these wires must be intended for more imposing duty, in-

asmuch as the poles are of an unusual design, as are also the insulators, while the nest of wires bridging the highway is surrounded by a kind of broad-meshed substantial network. This is a section of "transmission," as it is now laconically called in those territories where the conveyance of electric current is a familiar feature.

The North Wales system, which was carried out by the Edinburgh engineers, Bruce Peebles and Company, Limited, includes two main lines radiating from the power-station. The first installation comprised 26 miles of such transmissions of three-phase current at a tension of 10,000 volts. The main or heaviest transmission line, 9 millimetres in diameter, swings from the power-house in a westerly direction towards the Llanberis Pass, and thence to a point near Llanberis station, whence a spur runs to the Dinorwic Quarries to the north. The main line, however, swings round, strikes south, and then bends sharply to the west to Nantlle, the terminal being at the Pen-yr-Orsedd Quarries. The second line, composed of wires 8 millimetres in diameter, runs in an easterly direction towards Roman Bridge, where it bears to the south to gain the Oakeley Quarries at Blaenau-Festiniog.

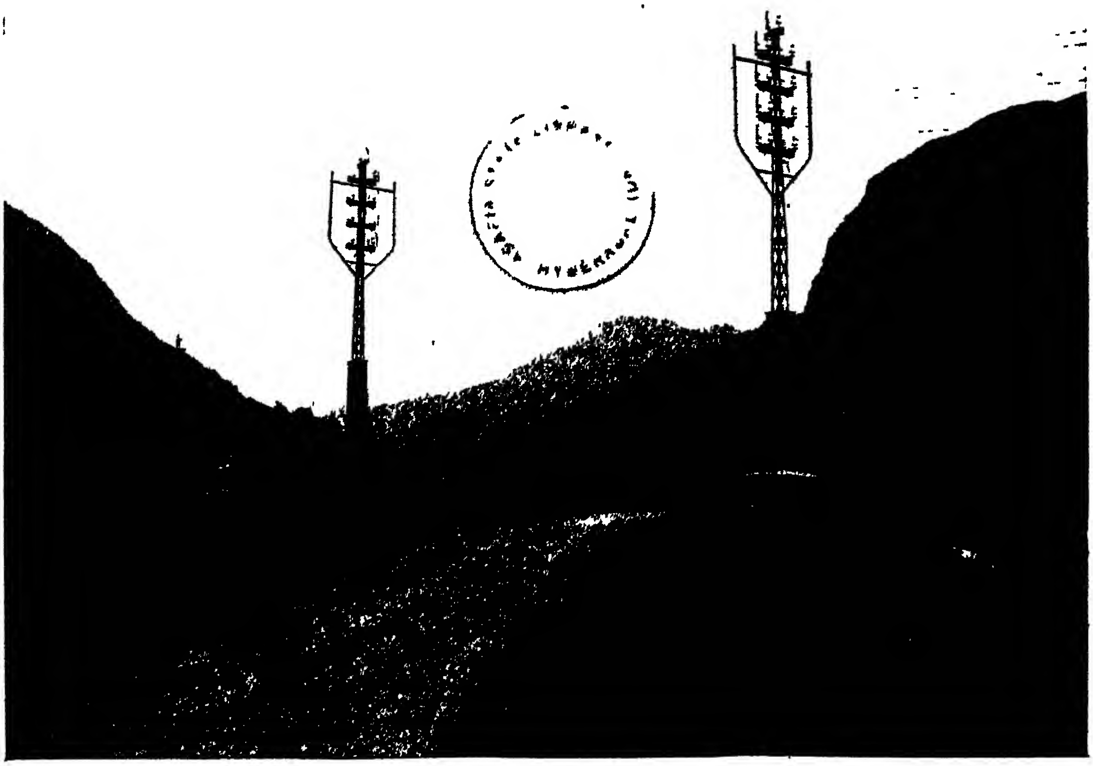
The construction of the Welsh transmission lines, though not to be compared with those carried out in many other parts of the world, either in point of length or difficulties overcome, nevertheless serves to bring home to one the complexities and perplexities incidental to such effort. It may be described as a miniature expression of the enterprise displayed in this field. Thus the route of the main transmission, extending to the Pen-yr-Orsedd Quarries after it turns south beyond Llanberis, is disputed by the mountain range of which Snowdon is the dominating peak. But the line climbs the shoulder of the mountain



THE ORIGINAL SNOWDON TRANSMISSION ZONE OF THE NORTH WALES POWER AND TRACTION COMPANY.

astride the route, reaching an altitude of 2,800 feet above the sea-level, and then drops down the other side to Quellyn Lake, turning to the west after crossing the North Wales narrow-gauge railway. The second transmission, running to the east, makes a bee-line over the mountains lying between the power-station and Roman Bridge before it bears to the south to gain its objective.

Owing to the difficulties encountered—topographical and meteorological—various types of poles had to be designed to meet the local conditions. For the most part creosoted wooden poles are used. These are spaced, on the average, forty to the mile, vary in diameter from 7 to 9 inches, and



WHERE THE MAIN "TRANSMISSION" SPANS THE HIGH ROAD THROUGH THE LLANBERIS PASS.
For the protection of passing traffic the wires, carrying the current at 10,000 volts, are enclosed by a cradle. Substantial construction of the line at this point was necessary owing to the severe climatic conditions which prevail.

are set in 6 feet of concrete to ensure rigid foundation. In some cases double-pole construction is favoured. On the Llanberis Pass section, owing to the abnormally severe weather which rules at certain periods of the year, the familiar wooden supports give way to heavier and more substantial, adequately stayed, steel lattice poles.

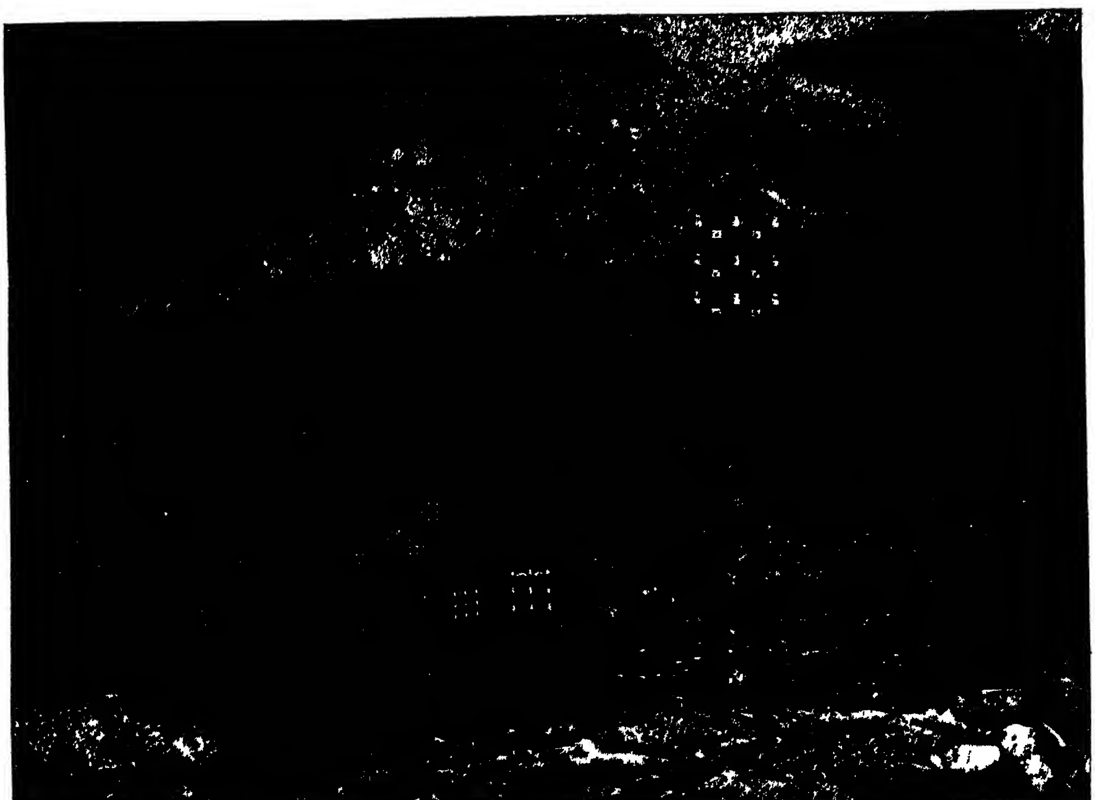
Getting the supports to the sites proved to be one of the most difficult and teasing incidents of the enterprise. At many places the ground traversed was found to be in a sodden condition, necessitating the construction of temporary corduroy roads for the haulage of material. Approximately 10 miles of tramways were laid down to facilitate this part of the work. Then at other places the rock put up a stern resistance and had to be rendered tractable by the persuasive powers of high explosives, the amount of blasting for such an undertaking being somewhat heavy.

The construction of a transmission line represents one phase of the task; its maintenance is another. The supply must be maintained at all hazards; a breakdown is likely to reduce the works depending upon such energy to idleness, more especially when an emergency system or supplementary source of supply is unavailable. Accordingly, the line is kept in close touch with the power-station by means of a telephone slung below the power wires for this purpose, which can be tapped at any point by the patrolman.

At the delivery points the wires are taken into the sub-station where the current is stepped-down, from the potential at which it is carried across the line, to the pressure

required for the operation of the various machinery, motors and other duties. The sub-station equipment in this particular instance includes high-tension switch-gear, to which the transmission line conveys the high-tension current, then to transformers, which reduce the potential from 9,400 volts at which it is received—certain losses being encountered in the transmission—to about 500 volts. Thence the current passes to the low-tension switch-gear controlling supply to the plant.

California, being pre-eminently the home of hydro-electrics, it is only fitting to find this state presenting some striking achievements in high-tension express transmission. The great centres of consumption, namely San Francisco, Los Angeles, Sacramento, and other cities, towns, and villages, are situate for the most part either upon or within easy reach of the seaboard, whereas the power-stations are built at lofty elevations among the snow-capped Sierra Nevadas where water is plentiful. The era was inaugurated by the installation for the Standard Consolidated Mine of Bodie, California, which was first brought into operation on August 18th, 1892. Alternating current was generated by a single 120-kilowatt single-phase generator, and the power was transmitted over a distance of 13 miles to the mine. As insulators and transformers underwent development, so did the distances increase over which the engineer essayed to transmit his power, until, at last, the stations situate high in the distant mountain range, amid the eternal snows, were linked up with Los Angeles, San Francisco, and other lucrative consuming markets by express transmission lines, many of which range up to 160 and even to 250 miles in length. The efficiency and service which has attended



THE NORTH WALES EXPRESS LINE APPROACHING ITS DESTINATION

In the background may be seen the terraces of the Dinorwic slate quarries, now dependent upon electricity. Twin-pole construction was adopted upon this section.

such operations has contributed to the more favourable acknowledgment by the public of the possibilities of electricity, which, in turn, has led to rising demands for power.

As an indication of the varied purposes to which electricity is industrially applied, it may be mentioned that, according to its gradation of consumers, the Pacific Gas and Electric Company, one of the largest and most successful of these consolidations, is maintaining forty-eight different commercial concerns with power. These, together with street-lighting, naturally absorb an enormous volume of energy, this exceeding 245,000 kilowatts during the year; but agricultural motors absorb some 137,000 horse-power, the manufacturing concerns 200,000 horse-power, mining motors nearly 50,000 horse-power, and railways about 100,000 horse-power. At the other end of the scale comes current consumed for heating and cooking, representing nearly 10,000 kilowatts.

Diversity of Electrical Service

In order to serve such a diversity of consumers, scattered over such a wide area, an intricate transmission and distribution system is necessary. The high-tension circuit exceeds 2,500 miles, of which nearly 400 miles carries current at a pressure of 120,000 volts*; 1,875 miles at 60,000 and 55,000 volts; 224 miles at 24,000 to 30,000 volts; and about 100 miles at 17,000 volts. In addition to the foregoing there are more than 6,000 miles of line in the distribution system operating below 17,000 volts, of which 5,700 miles are overhead, the balance underground.

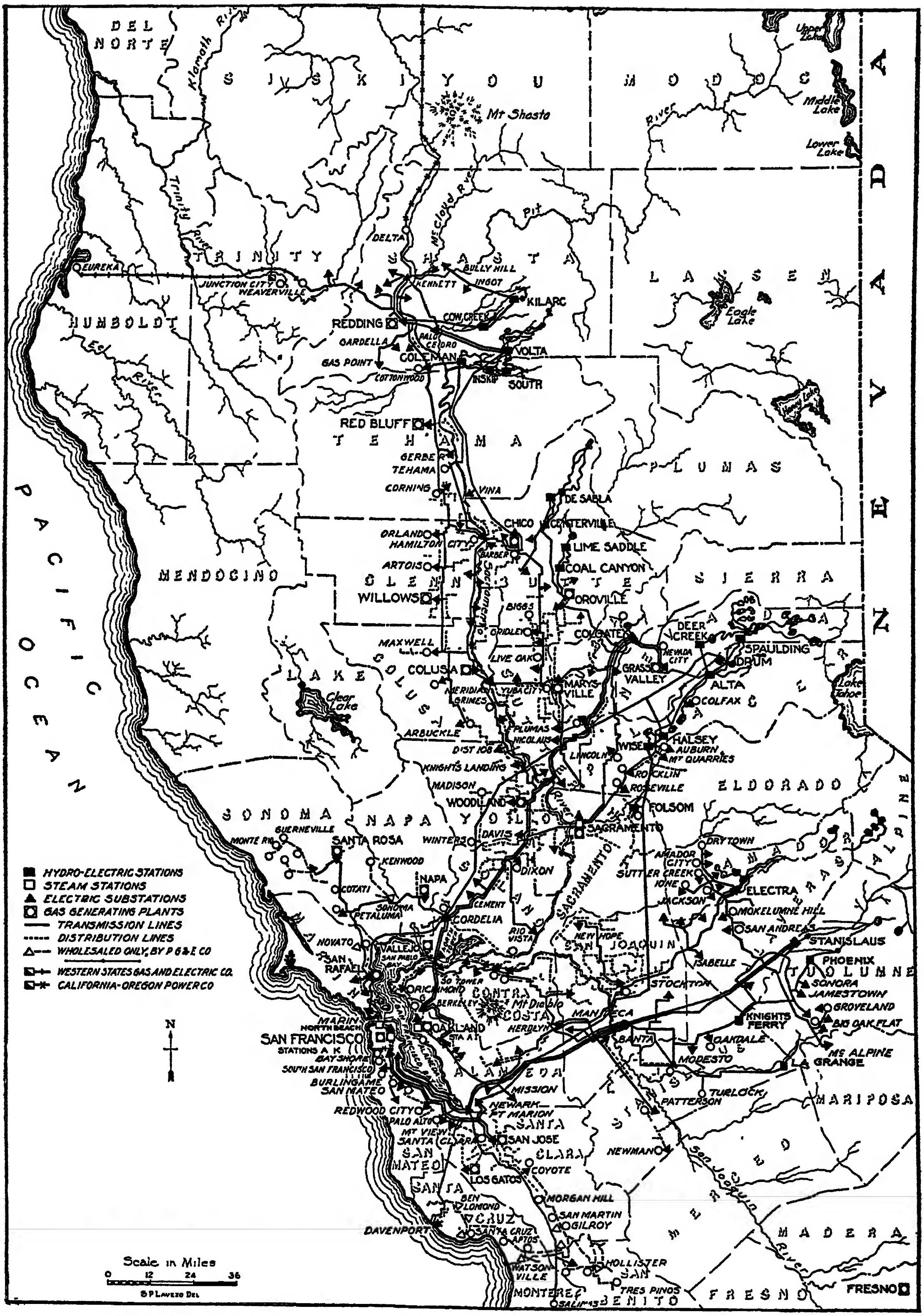
The most interesting trunk line naturally is that carrying the current at 120,000 volts. This is borne wholly on steel towers, 82 feet in height, having three steel cross-arms set one above the other, and in such a way as to give a clearance of 10 feet between each conductor. The suspension type of seven-disk insulator is favoured throughout. This is one of the most modern of the lines in the whole system, and is called upon to serve as an express conductor to San Francisco.

In bringing down the power from the elevated stations among the mountains to the coast, severely broken country is traversed, necessitating the introduction of several difficult spans. But the most spectacular of these is where the line is slung across the Carquinez Straits, the narrow neck of water connecting Suisun and San Pablo Bays, the large indents forming part of San Francisco Bay to the north of the Golden Gate. This is a navigable waterway, and, consequently, the engineers were called upon to give sufficient clearance to the masts of vessels using this channel. A huge span was inevitable, but, fortunately, the configuration of the land favoured the engineer in a somewhat audacious leap across this gap.

Carquinez Straits Span Details

Towers of steel of heavy construction were erected upon the brinks of the opposing cliffs, the north tower on Dillon Point being 191 feet in height. Massive construction of the towers was imperative, inasmuch as they are called upon to support two circuits. It was found impossible to reduce the main span to less than 4,427 feet, while at the same time ample clearance between the different conductors had to be safeguarded. The total length between the anchorages for the span is 6,292 feet, and although the wires naturally describe a pronounced graceful sag, the lower cable is 206 feet above extreme high water, thereby giving a clearance of 20 to 30 feet to the tallest-masted ships when riding empty at the highest level of the tide. The strain upon the cables is very heavy; they are also subjected to severe hostile forces, such as the high winds common to this part of the Pacific coast, and the deposit of moisture during the dense fogs which

* While these pages were in the press, a 220,000-volt express line has been put into operation.

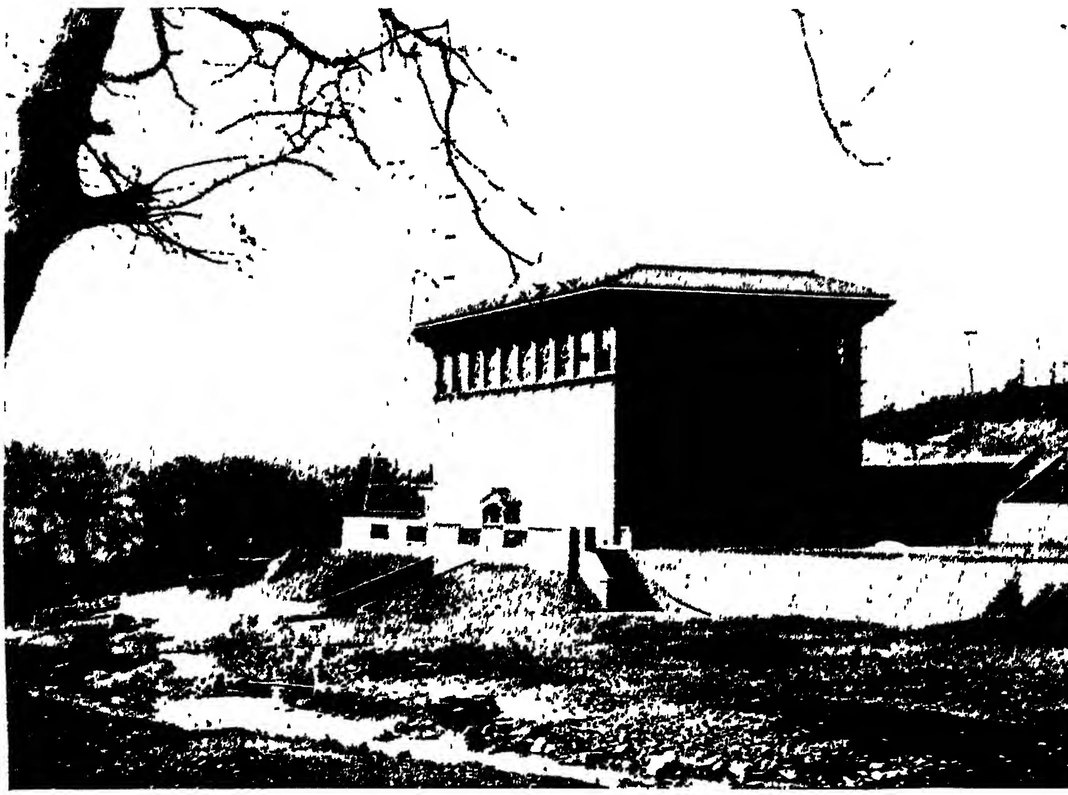


SKETCH MAP OF SOME OF CALIFORNIA'S ELECTRIC RESOURCES.

The intricate network of power-stations, transmission, distribution and bulk supply which has been woven by the Pacific Gas and Electric Company to satisfy the needs of San Francisco, Sacramento and other important centres.

frequently prevail, the weight of which accumulation upon the wires represents a considerable stress in itself.

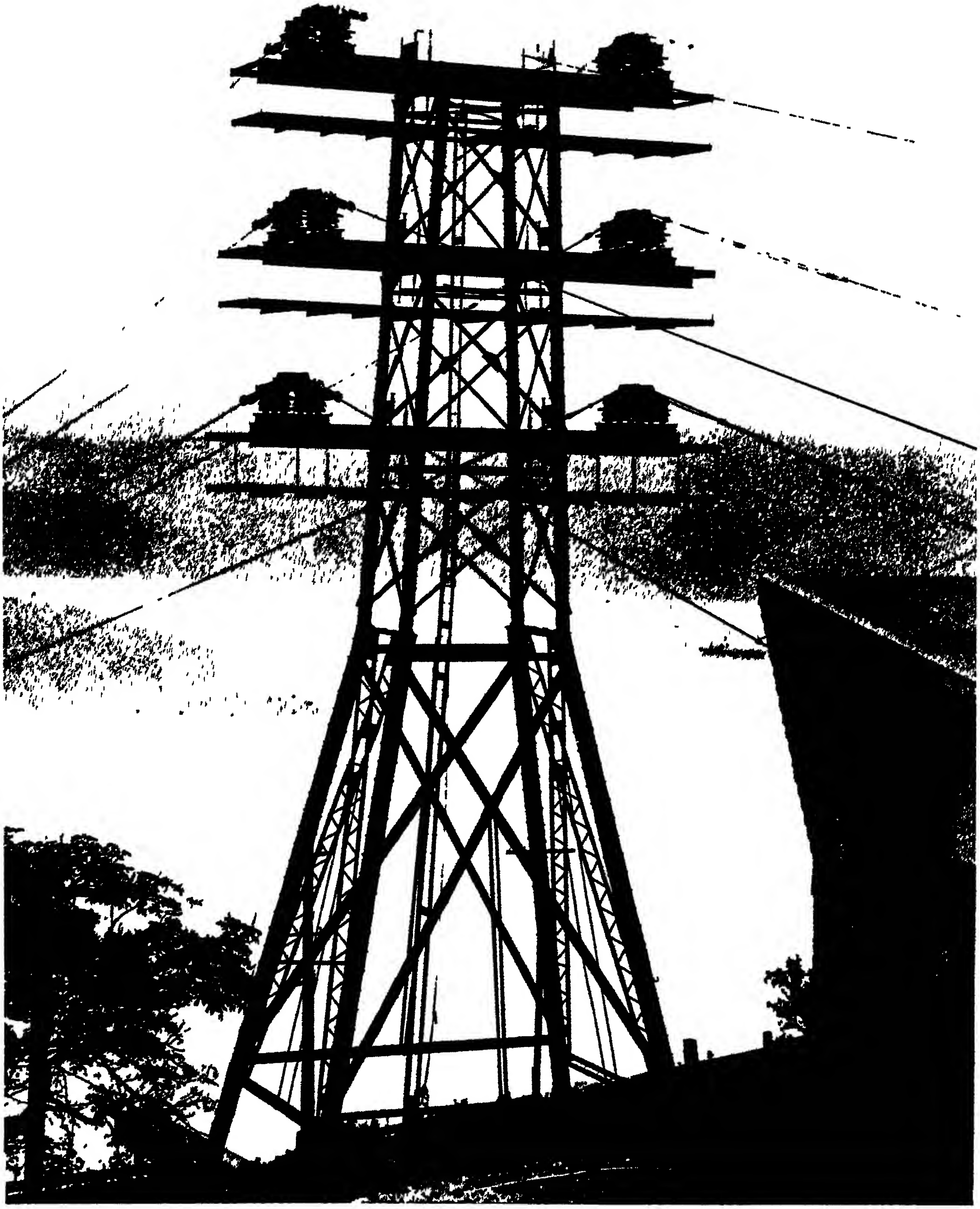
The maintenance of a high-tension system, especially in regard to insulators in connexion with such an extensive undertaking as the one under review, is a harassing problem. All told there are more than 100,000 insulators upon the high-tension service to be kept under constant surveillance. One might be disposed to think, bearing in mind the dimensions and weights of these indispensable adjuncts and the care bestowed upon their manufacture, that they would never occasion a moment's anxiety; but in point of fact they extend continuous employment to an imposing staff of trouble-men. The small boy is the enemy of the high-tension insulator, considering it an excellent target upon which to display his accurate stone-throwing proclivities; but he is equalled, if not surpassed, by the depredations of his contemporary armed with an air-gun or small rifle, who regards pot-shotting insulators as an equitable compensation for his failure to bring down game in the woods and forests. Between them these two antagonists account for an impressive number of damaged insulators during the course of the year, and are the constant butt against which the trouble-man expends his ire.



THE WISE POWER-HOUSE, ONE OF THE LINKS IN THE LONG CHAIN OF POWER-HOUSES OPERATED BY THE PACIFIC GAS AND ELECTRIC COMPANY

Architectural beauty has not been overlooked in the construction of modern generating stations In California the hydro-electric engineer is doing his best to preserve the amenities of the landscape

But the weather and the atmosphere are capable of wreaking quite as much havoc. Insulators are guaranteed to withstand prodigious strains, and are subjected to tremendous tests, but laboratory investigations with artificial conditions differ very markedly from practice. This is particu-



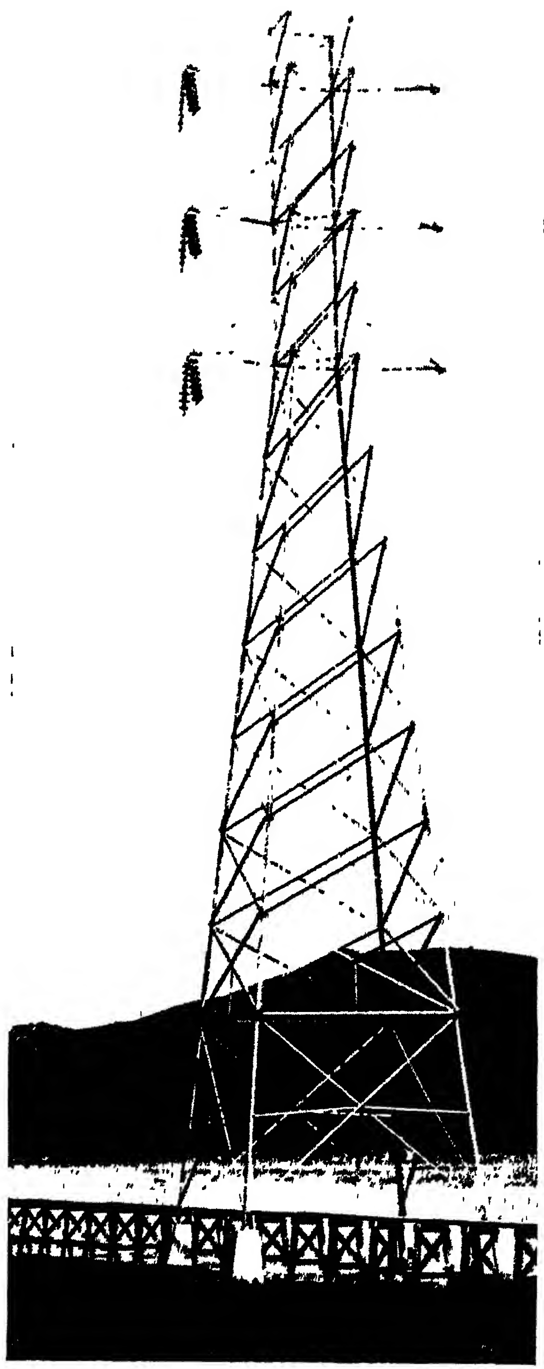
THE TRANSMISSION SWEEP ACROSS THE CARQUINEZ STRAITS, SAN FRANCISCO BAY.

To honour navigation rights the Pacific Gas and Electric engineers had to string their two 60,000-volt circuits across the waterway in a single span of 4,427 feet. The total length between anchorages is 6,292 feet, while the lowest cable is 206 feet above extreme high water.

larly the case in districts that fringe the Pacific seaboard, where dense fogs, high winds, dust storms and heavy rains are experienced. During the summer, when possibly friendly showers are few and far between, the winds pick up the fine dust and hurl it against the insulators upon which the particles secure a hold. Constant deposition of this dust will finally build up a bridge between the wire and the wood so extensively employed for the poles, especially upon lines up to 60,000 volts.

Furthermore, the vertical or pin-type insulator favoured upon these lines, instead of the suspended disk insulator employed upon the higher-pressure transmission, facilitates the accumulation of the deposit. When, subsequently, the dust becomes saturated, as for instance by a thick fog or light rain, it constitutes a conductor for the current which, leaking from the wire and coming into contact with the wooden pole, will set up a short-circuit of sufficient intensity to ignite the latter. Means for combating this danger are introduced, the shorting wire being run to the ground. This precaution probably saves the pole, but at the same time, as leakage is continuing, an arc is likely to be struck which either burns the transmission wire—causing a rupture—or shatters the insulator. However, generally speaking, the trouble-man would prefer to deal with a broken insulator or a burned wire rather than with a burned pole.

As a rule, if a dry dusty period is relieved by a short sharp spell of heavy rain, the dirt will be washed off the insulators, but reliance cannot be depended upon this function being fulfilled by natural agency. The difficulty is that, whereas dust and dirt will collect all over the insulator surface, more or less evenly, natural removal thereof is only likely to take place upon the side beaten by the rain. As prevention is better than cure the practice is to subject the insulators to periodical



HOW THE 120,000-VOLT CURRENT IS TRANSMITTED TO SAN FRANCISCO.

Standard steel tower of the Pacific Gas and Electric Company carrying two circuits. Each tower is 82 feet in height, while the three conductors are spaced 10 feet apart.

cleaning. The suspended type of insulator does not present the same anxieties, difficulties and liabilities to precipitate trouble. The surface is larger and, although offering increased harbourage for dust and dirt, there is a more extensive area upon which the rain can play, with the result that the natural cleansing operation is performed more effectively.

Insulator troubles are not to be lightly dismissed. They may become a serious burden to the company under the item "Compensation." Even the best-made and most sturdy-looking devices of this character, which possibly have emerged unscathed from most searching tests, will sometimes collapse at an unexpected moment for no cause which can be explained. Upon one of the Pacific Gas and Electric transmissions an insulator suddenly split into a dozen fragments. It was followed immediately by a terrific arc display which burned the line in two. The conductor came down with a run, the two ends falling amid a flock of 700 sheep. There was an outburst of spitting and fussing as the ends of the wire, seeking to revert to their original convolutions of the coil, whipped the animals. Twenty-four were instantly killed—electrocuted. Fortunately the collapse of an insulator nowadays is a rare occurrence, owing to the vast improvements which have been made in this indispensable auxiliary.

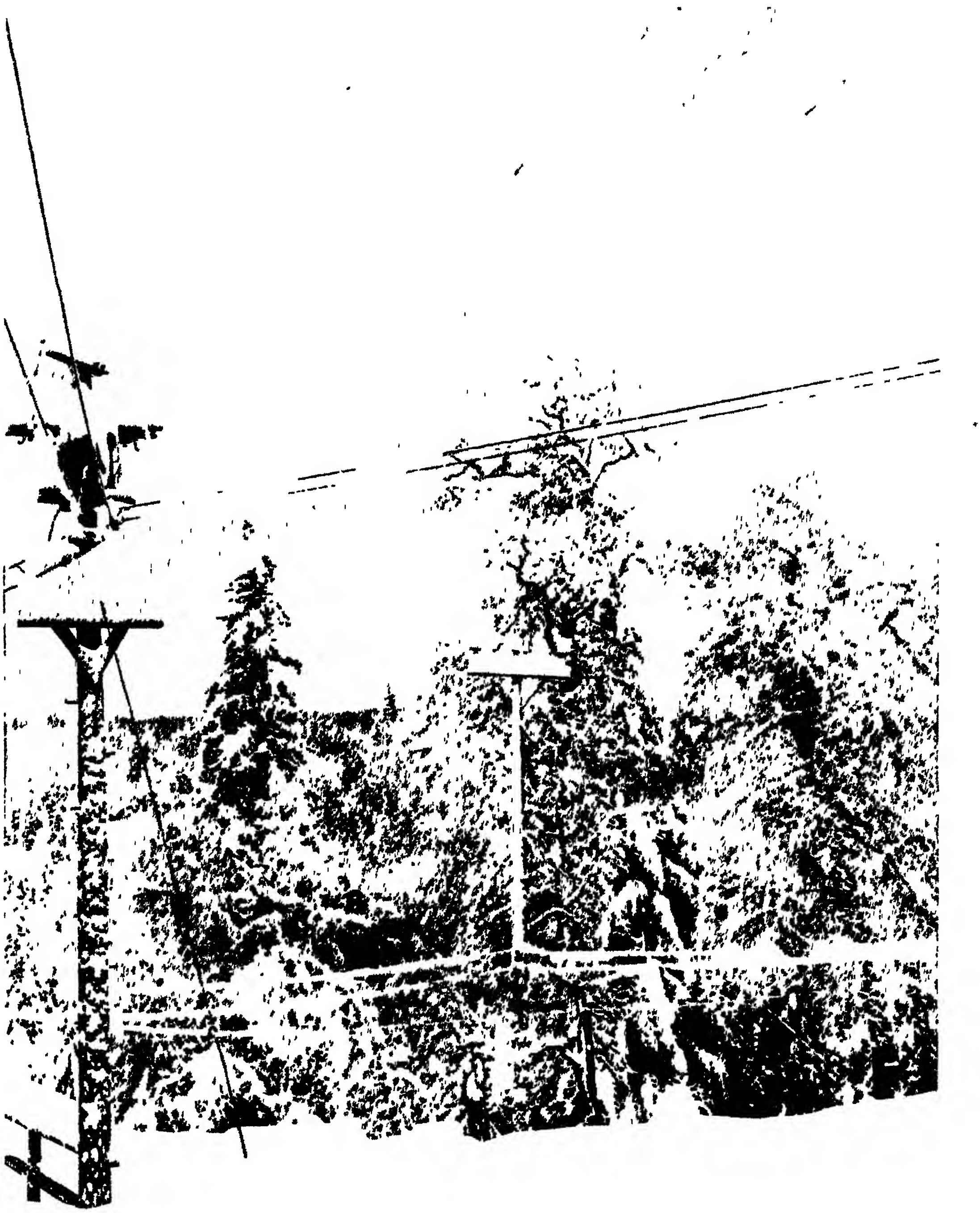
Terrific Arc Displays

Maintaining the transmission is not without its amusing aspects, although, if the truth were known, the trouble-men fail to appreciate the humour of the situation at the time, especially if the call should be received when wind and rain are indulging in their wild frolics, or a little relaxation from a somewhat peculiar round of toil is being sought. It is the small animals of the forest which are responsible for the majority of such troubles, either inadvertently or in the desire to satisfy a sudden wave of curiosity. The tree squirrel is undoubtedly the worst offender in this respect. One of these nimble little fellows swarmed a 60,000-volt line pole and, while dodging about among the insulators, set up a "short" between two of the wires, completing the circuit through his tiny body. Down came the line, and the ends set the dry grass ablaze. The collapse attracted the attention of some ranchers in the vicinity. They hurried up and promptly extinguished the flames. That line, through the playfulness of the squirrel, had to be shut down for some 12 hours while repairs were being made. A similar burn-out occurred less than five weeks later upon another forest section through a member of this family again electing to turn the cross-arms of the line into a playground. He likewise fouled the wires, with dire consequence to himself, and the ruffling of the placidity of the power-station and the urbanity of the trouble-men.

The domestic cat is generally invested with more common sense than to embark upon a voyage of discovery among the insulators upon the cross-arms of a high-tension line. One large cat, however, did prove venturesome in this respect to its intense surprise. It set up a terrific "short," bringing down the wire, which fired the grass and burned out a large wooden culvert carrying the country-road over a brook. The service upon the line was held up for some time, as was also traffic along the highway. The road, of course, had to be restored by the company. The trouble-man failed to find the cat, which must have been considerably astonished, even "shocked," by the treatment it received, but the repairer evidently saw the humorous side of the "break." He laconically reported: "That cat has but eight lives left; it forfeited one by trying to be a *pole-cat!*"

The Tale of a "Pole-cat"

Generally speaking it is the hostile forces of Nature which present the trouble-



THE "TROUBLE-MAN'S" LAMENT: "IT IS A KIND SNOW THAT BRINGS NO ONE A JOB!"

The white fleece of winter transforms the thin wires into fairy streamers, but the accumulated load imperils the line. Upon the mountain sections of the Pacific Gas and Electric transmission system, winter keeps the linesmen busy, because the fall is heavy and the drifts are deep.

men with their most formidable tasks. This is particularly the case among the mountains, notably in winter, when, from the high elevation of the generating stations and the transmission, the full fury of the blizzards and snow-falls is encountered. A heavy snow-storm will collect upon and transform the conductors, which possibly are about a third of an inch in diameter, into thick white fluffy cables four or more inches in thickness. The snow as it falls upon the wires becomes frozen into a compact mass, not only upon the upper half, but upon the under side of the wire as well. The visitor, happening upon the scene in brilliant winter sunlight, will probably grow ecstatic upon the picturesque fairy-land effects produced, the wires appearing like huge white scintillating streamers strung in graceful festoons from pole to pole. But the trouble-man, although quite as enthusiastic an admirer of beauty and Nature's decorative handiwork, nurses thoughts of quite a different character. He has visions of trouble without end all the while the snow is clinging to the wires. He knows that the slender strands of metal are being called upon to support many tons of additional weight which, in places, especially upon the longer spans, must be bearing down the conductors wellnigh to the point of collapse. Consequently, to him it is not a matter of beauty but how long the snow will remain on the wire, or will the conductor keep up?

Transmission must be Maintained

"It is a kind snow that brings no one a job!" This has become an axiom among the trouble-men whose duty it is to maintain "transmission service" at all hazards among the mountains. And when the line comes down and the fault has been located, it is not an enviable task wading through the white fleece, which has possibly drifted to a height of ten feet or more, to complete the repair. Sleds and snowshoes constitute the only means of locomotion. Grappling with ends of broken wire among the snow, swarming ice-covered poles, and making the joint with fur-gloved hands, with the thermometer hovering far below freezing-point, and a wind so piercing as to sear the face as if with a hot iron, effectively blunts the æsthetic sense. Moreover, the men cannot wait until the storm abates. The line must be maintained. Down in the low-lying country brilliant sunshine reigns with no more snow in sight than the distant mountain tops can present, but consumers have no thought of the trials and tribulations of the men struggling up among the clouds in their interests.

The Trouble-man's Risks

Power is demanded and in continuity, and it is the job of the trouble-man to see that the public is not disappointed, and that his company do not receive complaints about failure of service. These men would rather be listening to the rain falling in such torrents as if to presage another flood—"piling up the kilowatts" as they term it—than watch the soft feathery white flakes softly falling through the air. Nor is the duty without its tragic side. Accidents will happen, and the trouble-men are fully cognizant of this hazard. They know full well what will befall them if they should foul even a relatively low-pressure high-tension circuit. Despite care, and the observance of every precaution, misadventure will creep in. A mechanic, one of the most cautious, painstaking and experienced transmission men, was at the top of a pole carrying out a repair. The circuit had been "killed," but suddenly was energized through a current wire inadvertently fouling it. The trouble-man was instantly flung to the ground by the shock. He was picked up, but it was found that the full charge of current had passed through his body, killing him instantly. Electrocution is one of the risks, but, fortunately, it is rare, owing to the precautions laid down.

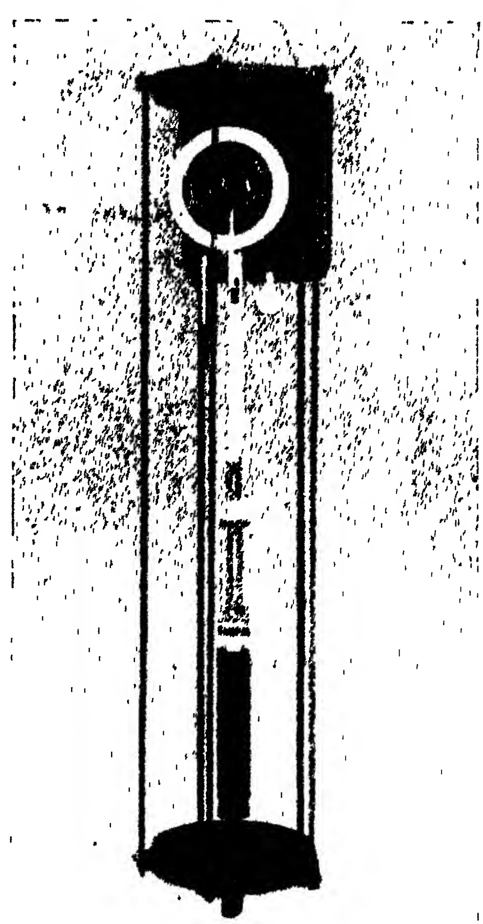
Taking the Spring or Weights Out of the Clock

TIMEKEEPERS WORKED BY ELECTRIC IMPULSES

FOR centuries the clock was regarded with almost reverential awe, so far as its mechanism was concerned. To have suggested any radical departure from the established principles of inducing the wheels to go round would probably have been regarded as sheer iconoclasm. True, certain improvements were made from time to time, such as Galileo's introduction of the pendulum, and Hele's employment of the mainspring instead of weights, to transform the timepiece into a portable instrument. However, these improvements did not disturb the fundamental mechanism to any pronounced degree.

To-day, however, we do not swear unswerving allegiance to the weight or spring as the source of energy for actuating our clocks. Electricity is disputing mechanical drive for supremacy, and, it must be admitted, is scoring heavily over its time-honoured rival. Not only has the electric current banished weights and springs from horology, but it has also wrought a significant departure in regard to the wheel-train, and brought about a striking revision of the design of that particularly sensitive device, the escapement. By the aid of this intangible force, the mechanism of the timepiece, no matter for what range of duty it may be designed, has been reduced to a degree of simplicity which would have been regarded as hopelessly impossible by the horological savants of a century ago.

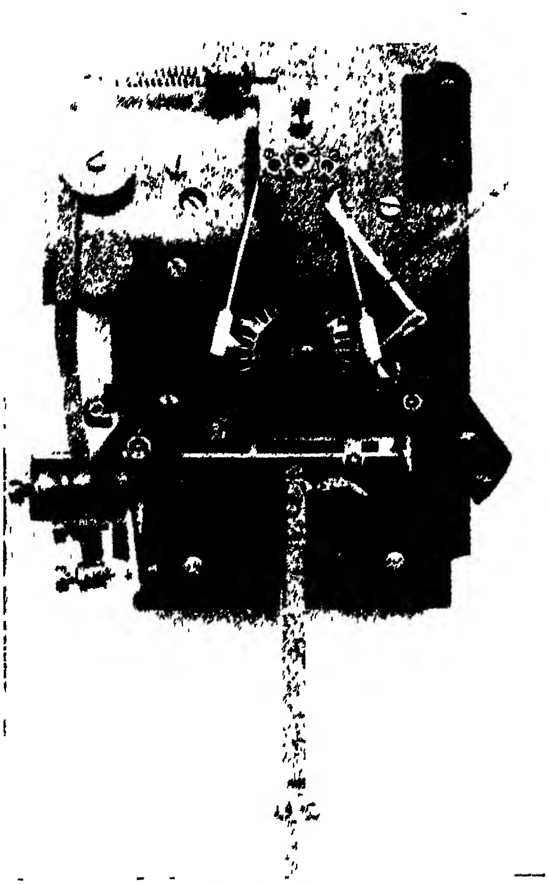
It was one of the British electrical pioneers, Sir Alexander Bain, who first set out to shatter deeply-rooted principles in this realm by employing electricity as the motive power. The ball of investigation, experiment and research once set rolling along a new channel, it was



ELECTRIC TRANSMITTER FOR OBSERVATORY CLOCK.

The "Pulsynetic" system as fitted to the Nizamian (India), Hong-Kong, and other observatories. The working parts are enclosed by a glass cylinder to ensure the pendulum swinging in constant pressure or partial vacuum, and to eliminate barometric error.

energetically pursued, with the result that many remarkable achievements have been placed on record. The development has not been confined to any one branch of the clock-making industry, but embraces all applications, from the mantelshelf timepiece to the huge turret-clock.



DETAILS OF ASTRONOMICAL TRANSMITTER.
All points and actions, as well as the escapement, are fitted with jewels.

The most notable developments have been in connexion with the control of a number of timepieces, disposed in a single circuit, so that one and all may show the same time, and for the operation of large turret-clocks respectively. Both are of far-reaching significance in their respective spheres. An extensive factory, public building, large commercial establishment, a mammoth ocean liner, or a busy railway terminus must necessarily maintain an extensive array of clocks. It is equally imperative that one and all should show the same time, for the avoidance of disputes, confusion and discrepancies in time records.

The electrically-operated clock, working in such a circuit, performs its task with uncanny precision, and considerable speculation obtains as to how it is done. The mystery is readily explained. At a suitable point a master-clock is established which not only shows the time upon its own dial, but communicates every impulse to the hand-moving mechanism of every other clock with which it is interconnected; a simple system of transmitting the impulses is employed. Obviously it is essential that the master-clock, or transmitter, should be a first-class timekeeper, because any error of which it is guilty must inevitably be reproduced upon the dial of every other clock with which it is in circuit.

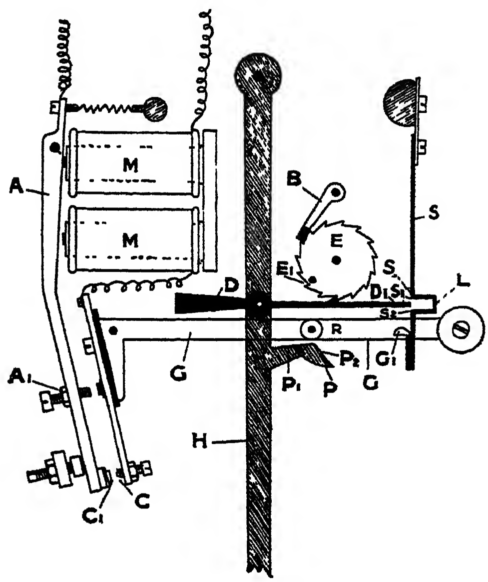
Many methods have been devised for operating clocks by electricity, but in the generally accepted leading systems the fundamental principle is the same throughout; the deviations in practice are confined for the most part to details. For the purposes of explanation, I have selected the "Pulsynetic" system of Messrs. Gent and Company, Limited, the well-known horologists of Leicester, which has been brought to a high standard of efficiency. As the transmitter constitutes the heart of the system, elaborate effort has been concentrated upon its perfection to secure unswerving fidelity and accurate movement under all and varying conditions. The pendulum is made of "Sin-evar," a nickel-steel alloy which has a very low coefficient of expansion, and wherewith the variations of the clock can be kept within two or three seconds per week—sufficiently near dead accuracy to satisfy ordinary commercial requirements. If the exigencies so demand, as for instance in the case of an observatory clock, the indispensable quality of absolute precision can be assured.

In this system the pendulum is impulsed, and the vibrations or oscillations maintained, entirely by that uniform and unvarying force—gravity. To secure the efficient application of this principle a new form of escapement, which might more accurately be described as a propelling feature, has been necessary. The pendulum hangs from a suspension spring which is carefully selected in relation to the weight of the pendulum, and the arc it is designed to swing, as well as the force of gravity which maintains this oscillation, is applied direct to the pendulum by means of a roller and pallet, instead of through a train of wheels and an escapement.

In the "Pulsynetic" system the pendulum is called upon to perform its designed duty at the moment when its kinetic energy is considerable, and therefore with the least disturbing effect.

The working principle of the transmitter is clearly illustrated in the accompanying diagram. The escapement wheel is represented by E, and there are 15 teeth in its circumference, one of which is cut more deeply than the others. This wheel can only be rotated in the forward direction; it is impelled forward tooth by tooth by the pawl D, and backward rotation is prevented by the pawl B. The escapement wheel completes a revolution once every 30 seconds; thus it is moved one tooth at a time every two seconds. The pendulum in swinging carries with it the pallet P (of the crutch H), which passes close under but without touching the roller R pivotally mounted upon the gravity or impulse lever G. With each oscillation of the pendulum the driving pawl D pushes round the escapement wheel E, so that at the end of 30 seconds, having completed a revolution, the driving pawl D falls into the deeper cut wheel tooth E^1.

At this moment the extension D^1 of the pawl D rises to engage with the stirrup catch S at the point S^1, whereas during the successive engagement of the pawl D with the preceding 14 teeth on the escapement wheel, the pawl extension has swung freely through the loop L. The supporting catch S is now pushed out of engagement with the gravity lever G at G^1 to permit the gravity lever to descend. In this release action the roller R, on the gravity lever G, drops first on to the dead face of the pallet P^1, and then, while the pendulum is



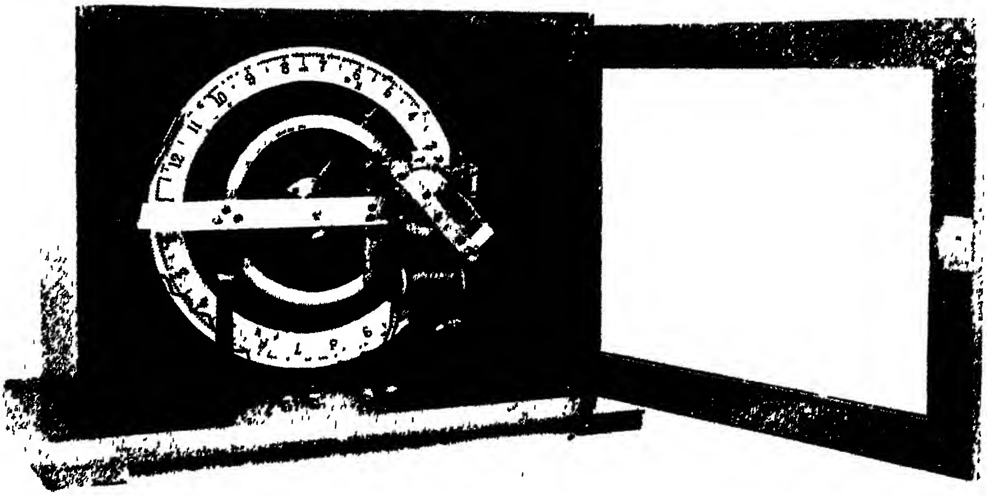
HOW THE TRANSMITTER WORKS.
Diagram showing the operating principle of the "Pulsynetic" mechanism.

swinging to the left, rolls down the inclined face P^2, thus imparting to the pendulum, in a mechanical manner, a gravity impulse of unvarying force.

The descent of the gravity lever is arrested at a predetermined point by the contact C mounted on the opposite end of the gravity lever G, because in the course of its movement it forms contact with C^1. The moment contact is established the electrical circuit through the electro-magnet M M is completed and the armature A attracted. As a result of the magnetic attraction, the armature A lifts the gravity lever G to its normal position.

At this juncture the breaking screw A^1 comes into play, arresting the movement of the armature, and interrupting the

contact between c and c^1, so that the flow of the current from the battery is checked, and the mechanism is returned to the normal position. The pendulum thus completes a further 14 swings, corresponding to the teeth on the escapement wheel, when the pawl D, again engaging with the deeper indent E^1 on the escapement, the cycle of operations is repeated to be continued unvaryingly until the battery is exhausted.



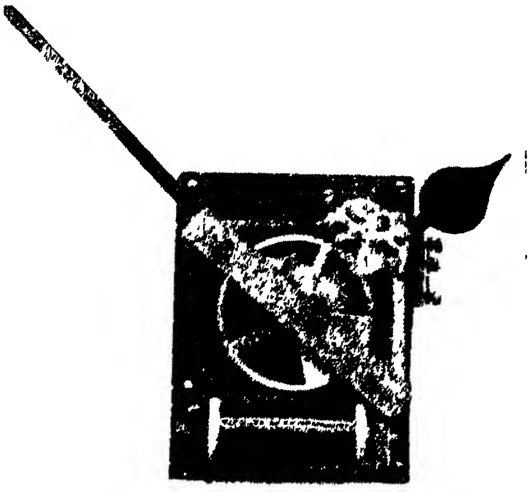
CLOCK-CONTROLLED CONTACT MAKER FOR THE AUTOMATIC OPERATION OF SYRENS, BELLS, HOOTERS, &c.

The large wheel, 12 inches in diameter, carries 288 holes, one for every 5 minutes of the 24 hours. By the insertion of pins in selected holes the device can be induced to sound at any even five minutes.

The duration of contact between the gravity lever G and the armature A varies according to the strength of the current. The make-and-break is quicker when the current flow is ample than when the battery is running down; the duration, therefore, is prolonged by the action of the contact taking place more slowly, thus increasing the time of contact, and giving all clocks in the circuit time to operate with the weaker current. The movement of the gravity lever and the recurrence of the impulse to the pendulum are always constant irrespective of the condition of the battery—a notable characteristic, conducing to accuracy of timekeeping.

Warning that the battery demands renewal or supplementing is given by a specially constructed inertia bell introduced into the circuit. Directly the strength of the current has fallen to a predetermined level, this bell rings steadily once every half-minute—at the time of periodic contact—until the requisite attention has been given to the system. Replacement of the battery should be made as soon as the warning bell comes into action, because during this period of notification the duration of the contact in the transmitter is a full second, whereas when the system is working smoothly the contact is only 1–30th second. A visual indication that the battery is failing is given by the transmitter. The gravity lever will be observed to remain down until the pallet P returns to the right to assist the gravity lever by pressing against roller R. An indication will also be given by each impulse clock, the working of which will be noticeably tardy.

Every clock in the circuit has the familiar wheel train movement supplanted by a simple device which may be varied



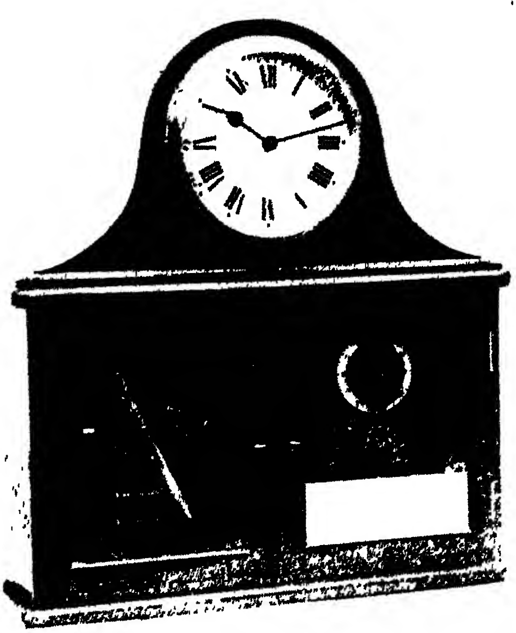
THE SIMPLE LOCKED MOVEMENT OF THE CLOCK
It is actuated by impulses received from the transmitter of the master clock.

within wide limits to meet any requirement. The simpler form comprises merely a ratchet-wheel having 120 teeth, with pawls and an electro-magnet. When the impulse is received—once every half-minute—the armature of the electro-magnet comes into action and impels the ratchet-wheel forward one tooth. The only additional mechanism required is the motion necessary to impart the requisite proportionate advance of the hour-hand to the progress of the minute-hand. The armature is so designed as to operate with a contact of exceptionally short duration with a very weak current.

Another great advantage accruing from electric operation is the facility with which any supplementary device may be introduced into and actuated by the circuit. Thus we have workmen's time-registers, bells, sirens, hooters—in fact any apparatus requiring automatic release at predetermined intervals with absolute synchrony. Some of these auxiliaries are of an interesting character. For instance, the hooter may be driven either by electricity or steam. If the former, an electric motor, fed from the public or factory service mains, is set going at the correct moment; the blast of the siren driven by it is maintained for so long, and then cut out as the motor is stopped.

Should steam be used then the ordinary bell-pull can be linked up. These arrangements can be so planned as to secure automatic suspension of action during the periods when the factory is closed, as, for instance, during the week-ends. Similarly, if desired, the signals can be arranged to sound at different times upon different days, while either suspension or modification of the programme for night periods can be secured with equal facility.

This automatic control of sounding devices, strictly according to the clock—that is to say, governed by the latter—has resulted in an important modification which extends the application of the principle to indefinite length. As the number of contacts which can be introduced to



IMPULSE TRANSMITTER FOR MARINE SERVICE
The electric master clock of the modern ocean greyhound is fitted with an advancing and retarding device to make the daily corrections for longitude upon all clocks throughout the ship.

one clock is limited, a special device has been elaborated. This comprises an aluminium wheel, 12 inches in diameter, provided with 288 holes, each hole representing a five minutes interval during the 24 hours. This wheel is also graduated in the hours and quarters to assist in setting out the time-table upon the wheel. Movable pins are introduced at the points desired, and as the wheel is rotated by impulses from the transmitter, contact is established at the desired minute, the sounding device automatically brought into operation, and discontinued when desired by the breaking of the circuit in due course.

Another interesting development which deserves mention is the coupling-up of the time-recorders provided in factories with the "Pulsynetic" electrical time circuit, for checking the workmen in and out. This not only assures synchronization of the time-recorders, but compels them to keep in agreement with the timepieces distributed throughout the works. Nothing is more annoying to the management than disputes with their employees regarding the varying time-keeping of the recording clocks. Differences of this character provoke discontent, friction with the workers, and disorganization of the system of management and output laid down.

Synchronous Time-recorders

Experience has proved at factories where two or more recorders are in operation, that, frequently, a man checking-in at one instrument is clocked-out, and probably is not permitted to start work; but a fellow-worker, arriving later, who checks-in with another instrument is duly clocked-in. Naturally, the first worker voices a grievance; he labours under the impression that he is being victimized, whereas in actual fact the unfair treatment is due to the different time-keeping qualities of the two recorders.

In order to eliminate this source of contention the horological experts at the Faraday Works set out to devise ways and means of bringing the recorders into unison. It was not a simple problem, inasmuch as the incorporation of any mechanism to achieve the desired end had to be executed in such a manner as to be independent of the recorder mechanism. Any interference with the latter would immediately absolve the recorder-maker of all responsibility for the accurate operation of his instrument.

The situation has been met by the "Reflex" pendulum control worked from the transmitter. A spring attachment is clamped to the pendulum of the register-clock while the control device, a wholly distinct piece of mechanism, is screwed to the register case and connected to the time circuit. All this simple control does is to compel the pendulums of all the recorder clocks to beat in unison and to synchronize with the transmitter controlling the time circuit and the other clocks in the circuit. The construction of this attachment is such that, in the event of the electrical circuit suffering interruption, the recorders continue working in precisely the same way as before the device was fitted—but uncontrolled.

The perfection and reliability of the electrical timepiece is strikingly demonstrated by its introduction upon mail-carrying and other liners, and in observatories where, as is well known, absolute precision is imperative. So far as marine service is concerned it is necessary to make daily correction of the time in accordance with the difference in longitude, the clock being retarded when travelling west and advanced when eastward bound. In this instance the master-clock is fitted with a jewelled lever escape and chronometer balance instead of a pendulum. To correct the clock according to longitude difference the transmitter is provided with a special device, which not only adjusts the master-clock but all the

On Marine Service

secondary dials distributed throughout the ship in circuit with the master.

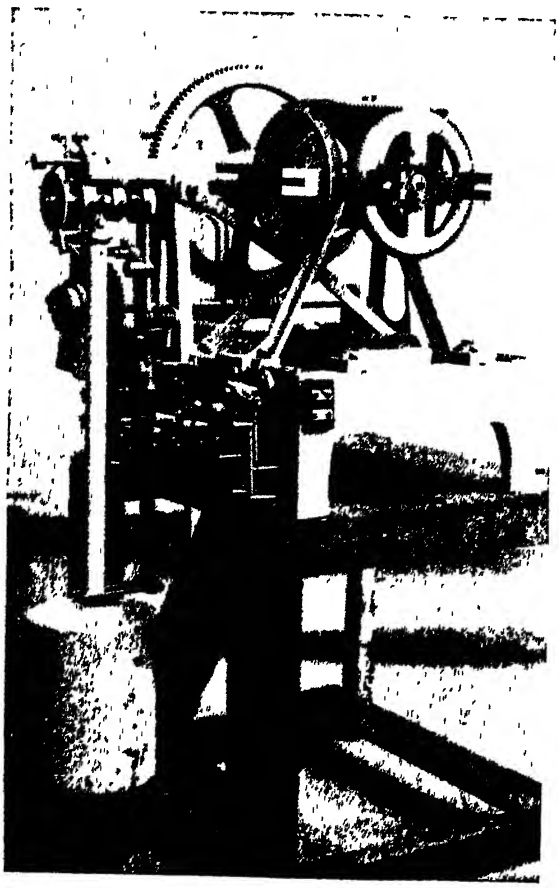
When proceeding against the sun—that is, in the eastward direction—it is only necessary to set a pointer to the number of minutes it is desired to advance the clock, in accordance with the longitude reading. The whole of the clocks are then simultaneously advanced to that extent; while when overhauling the sun a similar operation is carried out, but in the reverse direction, to obtain the desired retardation.

So far as the observatory timepiece is concerned the salient difference from standard commercial practice is the observation of means to secure the indispensable scientific accuracy. For the most part this involves a more careful selection of metals endowed with enhanced resistance to wear and other adverse influences, fabrication of the parts to dead micrometer measurements, and the fitting of jewels to all points and actions. One modification of the general principle, which has already been described, is the release of the gravity lever at each alternate swing; the releasing operation takes place with the minimum of friction, at a point in the swing of the pendulum where its timekeeping is least disturbed. As a rule, the astronomical observatory clock is bolted directly to the stonework of the building and the working parts enclosed in a glass cylinder, thus allowing the pendulum to swing in constant pressure or partial vacuum, and securing the elimination of barometric error.

While the adoption of the electrical system of operation and control of clocks has accomplished significant developments in the factory and the commercial building, its many advantages are just as strikingly revealed in connexion with the large timepieces distinctively known as turret-clocks. Here certain new problems arise. The dimensions of the dials of such timepieces are probably larger than is generally imagined, while, owing to exposure, the hands are subjected to influences which never assail the indoor clock. The hands are heavy and have to be carefully counterbalanced, otherwise, under the force of gravity, they would tend to press the motion forward in descending from XII to VI, and to act as a brake while ascending from VI to XII. The relatively extensive surface against which the wind can bear causes the hands to rock to and fro upon their bearings; while in a snow-fall or a blizzard the work of the hands is intensified. Occasionally, the movement of the old type of clock will be stopped, because the energy imparted by the falling weights within the tower is unable to overcome the adverse external forces of Nature.

THE SIMPLE MOTION FOR TURRET-CLOCK HANDS.
This is driven by the waiting-train movement, giving positive action to the hands.

In applying the electric drive to turret-clocks these hostile forces must be taken into consideration, and adequate allowance made therefor. The most successful means of achieving the end in view has been attained by the employment of the "Pulsynetic Waiting-train" movement, which provides practically unlimited power for driving the hands, and yet is completely subservient to the time-transmitter. Thus we have the curious situation of the hands

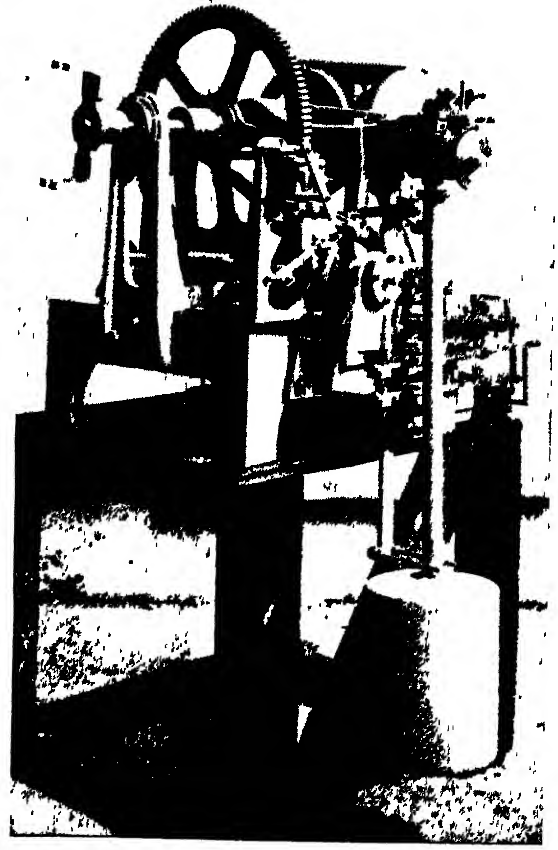


THE "WAITING-TRAIN" MOVEMENT FOR ELECTRICALLY-DRIVEN TURRET-CLOCKS.

Showing the bevelled gear-wheels, driven by the central horizontal crown-wheel, to which the motion for moving the hands of a multi-dial clock is coupled. At the side, in the lower frame, may be seen the electro-magnet which actuates the motor-pendulum in driving the hands.

contesting vigorously the terrific onslaughts of the weather, while being kept under such perfect control that absolute accuracy in regard to time is maintained.

Here again success has been accomplished by the elaboration of an extremely simple movement, notwithstanding the complex problems involved. The outstanding feature of the waiting-train movement is the "power-factor." There is a pendulum which is driven by impulses given by an electro-magnet. This electrically-driven motor-pendulum has nothing to do with keeping time, but is designed to keep the hands in steady uniform movement. The latter are mounted at one end of a shaft, the other end of which carries the counterbalancing weights, and a simple motion of worm-gearing. It is the function of the motor-pendulum to drive by means of a pawl, a ratchet-wheel, tooth by tooth at each vibration. This ratchet-wheel in turn, through the worm-gearing mentioned, thus forces the hands of the clock forward with practically a continuous motion. The motor-pendulum does not receive its impulses in a steady manner at definite intervals, since its pulsations are not comparable with those of an engine, but are distinctly spasmodic or irregular, and are



ANOTHER VIEW OF THE "WAITING-TRAIN" MOVEMENT.

The pendulum, which is energized by an electro-magnet to maintain its oscillations above a predetermined arc, works solely for the positive movement of the hands. Beside the large gear-wheel may be seen the magnet, which moves the escapement by the impulses received from the transmitter.

dependent upon the resistance which the hands are encountering to their steady progressive movement.

The motor-pendulum is kept in constant oscillation, but it only receives a boost from the electro-magnet when its swing falls below a predetermined arc. Under normal conditions the pendulum will not require re-energization more than once about every 60 seconds; but the moment heavy work is imposed upon the motion, as for instance when the hands are fighting their way against a heavy wind, the electro-magnet takes up the duty. If the conditions so demand, re-energization will take place once every complete vibration of the pendulum, in which event the motor-pendulum attains its maximum effort, which is about 30 times that recorded when re-energization is occurring only about once a minute. Under such conditions the power exerted is such as to render it impossible for one to arrest the forward movement of the hands, even by the exertion of one's full power upon the worm-wheel.

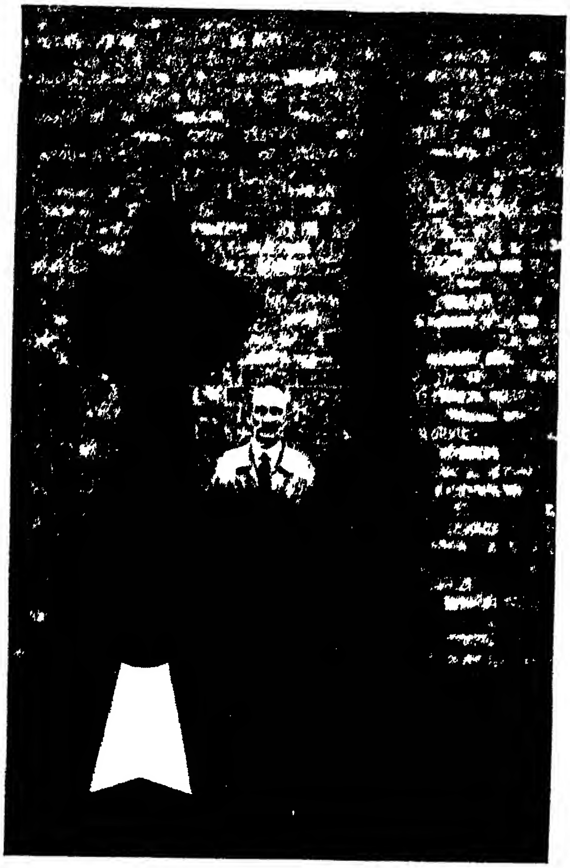
The system of control is somewhat differ nt from that of the impulse method previously described. The gear ratio of the hand motion is such that the minute-hand is driven through the space on the dial representing a half-minute in approximately 27 seconds. Then the pawl of the motor-pendulum is lifted out of engagement with the teeth of its ratchet-wheel, thus bringing the latter to a standstill, although meanwhile the motor-pendulum is continuing its normal swinging action. But the disengagement of the hand-motion from the pendulum causes the former to stand still for two or three seconds, being firmly locked in that position by the worm-gear. At the 30 seconds' interval an electric current impulse, dead on the half-minute, comes through from the transmitter, releases the pawl, and the hands are moved steadily forward the space of another half-minute on the dial, when the cycle of operations is again repeated. Accordingly, in describing a complete circle of the clock, corresponding to the hour, the hands appear to move forward in a steady progressive manner.

This control is extremely simple and strikingly efficient. No separate battery or contacts are required for the control, the half-minute impulse from the transmitter, which is kept in the base of the tower or some other position where excellent timekeeping can be assured, doing all that is required. Some idea of the perfection of the system may be gathered from the fact that even with the largest turret-clocks, with dials running up to 20 or 25 feet in diameter, and wherein the minute-hand is necessarily a heavy

THE LARGEST ELECTRIC CLOCK IN THE WORLD. It is mounted in the turret of the Royal Liver Building, Liverpool, 220 feet above the pavement. Each dial measures 25 feet in diameter, and the minute hands each measure 14 feet in length. The total weight of the clockwork is about 6,700 lb., and more than 35,800 lb. of iron and opal glass were worked into the four dials.

adjunct, accuracy within one second per week can be assured—a result due to the driving mechanism being preserved distinct from the timekeeping device.

The elimination of the ordinary array



A PAIR OF HANDS FOR AN ELECTRIC TURRET-CLOCK WITH A 16-FEET DIAL.

of wheels not only simplifies the mechanism to a very material degree, but enables such components as are essential to be of adequate dimensions to ensure durability. Cleaning and replacement of parts, when necessary, are also facilitated, while the cost of upkeep is reduced to an insignificant item. The improvement which electricity has wrought is obvious from the fact that a movement, capable of driving two 9-feet, or four 8-feet dials, weighs only 150 lb. complete, while the smallest wheel of the movement, together with the arbor to which it is screwed, weighs 24 oz. The waiting-train movement can be accommodated upon a small wooden bench in the chamber behind the dial. When a four-dial clock is installed the movement is set centrally in the space; the four sets of hands are driven from the one movement through connecting rods, one extending to each dial.

The electrification of the turret-clock movement, with the elimination of all weights and drums, facilitates the introduction of striking and chiming mechanism, carillons and other devices requiring time-control with automatic connexion and release. This feature may be actuated by a modification of the waiting-train movement, and driven by the hour-spindle of the latter. As the circuit is interrupted after each blow of the hammer upon the bell, Leclanché cells may be employed for this purpose. Another arrangement involves the employment of a direct-current motor actuated by power drawn from the public supply service, a plan which is generally favoured when the bells range from 2 tons upwards in weight; the mechanism is then timed by an hourly contact-maker driven off the impulse circuit. In a similar manner, where the dial is illuminated, automatic devices bring the illuminant into play and extinguish it at the time desired in accordance with the seasons. The controlling feature is a cam, the curve of which is so cut as to coincide with the seasonal changes. By means of worm-reducing gear this cam is induced to complete a revolution only once in 365 days, so that as the days grow longer the time for lighting-up is retarded, and similarly advanced as the days grow shorter; the extinguishing apparatus is correspondingly regulated. This arrangement only requires correction once in four years to meet the occurrence of leap year.

The electrically-driven clock achieved its greatest conquest when the "Pulsynetic" system was adopted for the embellishment of the tower crowning the Royal Liver Building in Liverpool, one of

the largest commercial palaces in the British Islands. This is the biggest electric clock in the world; each of its four dials, set 220 feet above the pavement, is 25 feet in diameter, thus eclipsing the dials of the famous Big Ben of Westminster, which measure 22½ feet across.

Owing to the severity of the gales which rage off the estuary of the Mersey, and the exposed position of the clock, due to its elevation, special attention had to be devoted to the design and construction of the faces and the hands. The framework of each dial is massive; 3½ tons of iron are required to carry the 660 lb. of opal forming the face, which is of sufficient thickness to withstand a wind pressure of 11 tons per square inch. The total weight of the four dials is, therefore, nearly 16 tons. The hands, made of sheet copper reinforced with gun-metal ribs, are imposing; each of the minute hands is 14 feet in length by 3 feet in width in the centre. The minute intervals, inscribed around the outer circle of the dial, are spaced 14 inches apart, so that the point of the minute-hand travels 840 feet every hour. Instead of the usual Roman numerals to denote the hours, twelve solid black uniform marks, 3½ feet in length by 18 inches wide, form the chapters and enable the time to be read easily from a considerable distance.

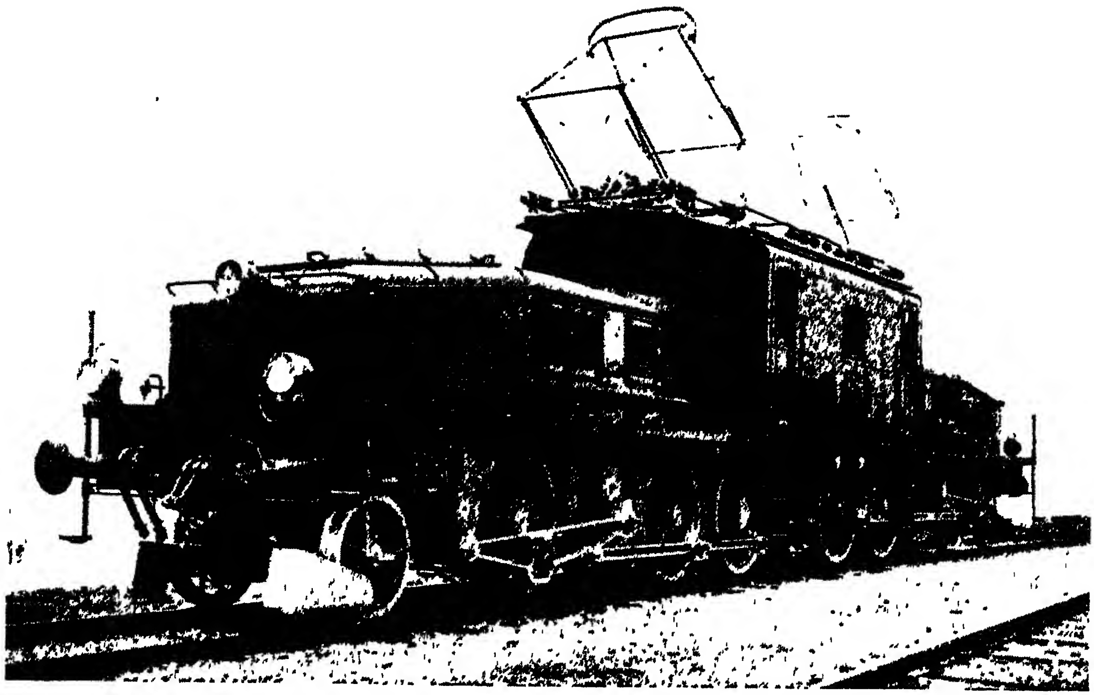
Electric Light Automatic Device

The mechanism is the waiting-train, which has been described in detail, and its total weight is only 3 tons. That the disassociation of the timekeeping portion of the clock from the hand-moving mechanism does not impair the timekeeping qualities is evident from the circumstance that an accuracy of approximately two seconds a week is maintained. The automatic device for switching on and off the electric light illuminating the dials from within at the desired times at dawn and dusk respectively, follows the standard lines, except that in this instance the controlling cam completes its single revolution once every two years.

A novel method of emphasizing the unique dimensions of the dials fitted to this clock is worthy of record. After one of the faces had been completed, preparatory to its dispatch to Liverpool, it was transferred to the Free Trades Hall in Leicester, where it was laid in a horizontal position upon an extemporized support to form a dining-table. Fifty guests were invited to partake of the luncheon set out upon this quaint festive board, and they were seated with complete ease. The glass and ironwork were then dissembled and dispatched to Liverpool for permament installation in the tower.

Big Ben "Movement"

The significance of the utilization of electricity for the operation of such a huge turret-clock — huge, that is, from the time-indicating point of view as represented by the dials—may be realized very readily when compared with the largest British mechanically driven clock—Big Ben. The "movement" of the famous clock at Westminster is contained in a massive frame 15½ feet in length by 4 feet in width. Upon this is mounted three trains or sets of wheels; the largest is about 3 feet in diameter. Each train is driven by its own weight. In the centre of the frame is the "going" or watch train; while at one end is the chiming train, and at the other the hour-striking train, both of which are released at the correct moments by the "going" train. The pendulum is approximately 13 feet in length, and weighs nearly 700 lb. Comparison of the Westminster and Liverpool clocks, of broadly equal dimensions from the "service" point of view—time-indication—is interesting. The one is typical of practice established for centuries, while the other is illustrative of the latest trend of horological science, and asserts the supremacy of electricity in this sphere.



ELECTRIC FREIGHT LOCOMOTIVE FOR THE ST. GOTTHARD RAILWAY.
Three-quarter end view of the 2-6-6-2 unit built by the Ateliers de Construction, Oerlikon, showing the method of transmitting the power from the motors to the coupled driving-wheels.

Electric Operation of the St. Gotthard Railway

HOW SWITZERLAND IS TURNING TO HYDRO-ELECTRICITY TO SAVE IMPORTATION OF COAL

THE railway network of Switzerland may be divided into two broad classes. There are the mountain railways dependent essentially upon tourist support for their prosperity, and there are the standard and narrow-gauge trunk roads providing intercommunication and linking up with the systems of the surrounding countries. For the most part the mountain railways are operated electrically, and it is their success which has prompted the extension of this form of energy to the main lines. This decision must inevitably react to the economical advantage of the country. When the schemes in hand are completed, toll will no longer be paid to other nations for fuel, because water-power is abundant.

The electrification of the big tunnels was discussed some years ago, but the project failed to materialize owing to the mixed control which prevailed. Whereas some of the roads were the property of private undertakings, others were owned by the State. To facilitate future developments,

the Government set out to weave the railway system into a homogeneous whole by acquiring the private lines. Upon the completion of the Simplon and Loetschberg roads, the authorities embarked upon a series of searching experiments to determine the most satisfactory foundation upon which to create the electrical fabric.

When the pioneer Swiss Alpine railway and tunnel, the Lucerne-Chiasso system, more popularly known as the St. Gotthard line, passed into the hands of the State, it was decided to convert it to electrical working without delay. Electrification was not to be confined to the actual tunnel, 9½ miles long, but the whole of the road from end to end, a distance of 140 miles, was to be converted.

This artery of steel is an outstanding achievement of the railway plotter and engineer. Grades and curvature are heavy. At Lucerne the metals lie approximately 1,438 feet above sea-level, and for the first 31 miles—to Fluelen—the road is gently undulating. After leaving the latter point the great climb to the summit commences; a difference of 2,201 feet in level has to be overcome during the succeeding 24 miles. This brings the railway to the Goeschenen portal of the tunnel through which a gradual rise continues to near the central point, which represents the summit level of the line. Then commences the descent, imperceptible at first, because it is in the heart of the mountain, but after clearing the tunnel at Airolo it becomes sharp, while the total fall during the 41½ miles

BY ELECTRICITY THROUGH THE ST. GOTTHARD TUNNEL

Working under steam conditions through this 9 miles bore through the Alps was attended by many disadvantages, including that of fouling by steam and smoke. In this picture the express, hauled by a Brown-Boveri electric locomotive, is shown emerging from the tunnel

to Gubiasco is 2,991 feet. Through the last section the road rises and falls until it finally reaches Chiasso, 737 feet above sea-level.

For the electric operation of the railway the single-phase system has been adopted; the pressure upon the overhead conductor is 15,000–7,500 volts, with a frequency of 16⅔ cycles per second. The original intention was to proceed with the electrification project somewhat slowly, so as to be able to take practical advantage of the results of the experiments which were being conducted with various types of locomotives, but the outbreak of war in 1914 precipitated a crisis. The country was threatened with a coal famine from the inability of the nations upon which it had hitherto been dependent to make shipments. The prospect of the railways being condemned to immobility through lack of fuel was serious.

Experimental Locomotives

Electrification was expedited, and locomotive construction was confined to the types which had proved satisfactory upon the Simplon and Loetschberg lines. Nevertheless, pressure did not completely stultify evolution, because the domestic firms identified with this branch of activity were encouraged to give effect to their individual ideas, especially in regard to details. Consequently, during the war period many interesting locomotives were designed and built, and these have proved highly satisfactory in service. Each type is distinctive, though fundamentally it coincides with the specifications laid down and resulting from the experiments to which reference has been made.

Two of the express locomotives were built at the Ateliers de Construction, Oerlikon, and are representative of the 2–6–2 and 2–4–4–2 classes respectively; the latter is the heavier and more powerful unit. Their essential features are :—

	2—6—2	2—4—4—2
Length over buffers ..	44 ft. 3 in.	53 ft. 1 in.
Driving-wheels, diameter..	4 ft 6 in.	4 ft. 6 in.
Trailing-wheels, diameter..	3 ft. 1 in.	3 ft. 1 in.
Weight of mechanical parts	46·5 tons	58·5 tons
Weight of electrical equipment	44·5 tons	54·5 tons
Total weight	91 tons	113 tons
Available weight for adhesion	58·5 tons	80 tons
Power developed at rail at 1½-hour rating ..	1,650 h.p.	2,250 h.p. approx.
Tractive effort at 1½-hour rating .. .	19,530 lb.	26,400 lb.
Maximum tractive effort .	29,700 lb.	32,600 lb.
Normal speed .. .	31·25 miles	31·25 miles per hour
Maximum speed	44·5 miles	44·5 miles per hour

These locomotives were designed to haul a train of 425 tons; with this load the heavier and more powerful unit is assisted by the smaller engine upon all banks exceeding 1 in 47. The hauling capacity of the smaller locomotive is 216 tons upon banks of 1 in 38 at the normal speed of 31·25 miles an hour. Under the same conditions of speed and grade the 2–4–4–2 type can draw a train of 300 tons. Each locomotive, upon a bank of 1 in 38, is able to attain the speed of 31·25 miles an hour within about four minutes of starting.

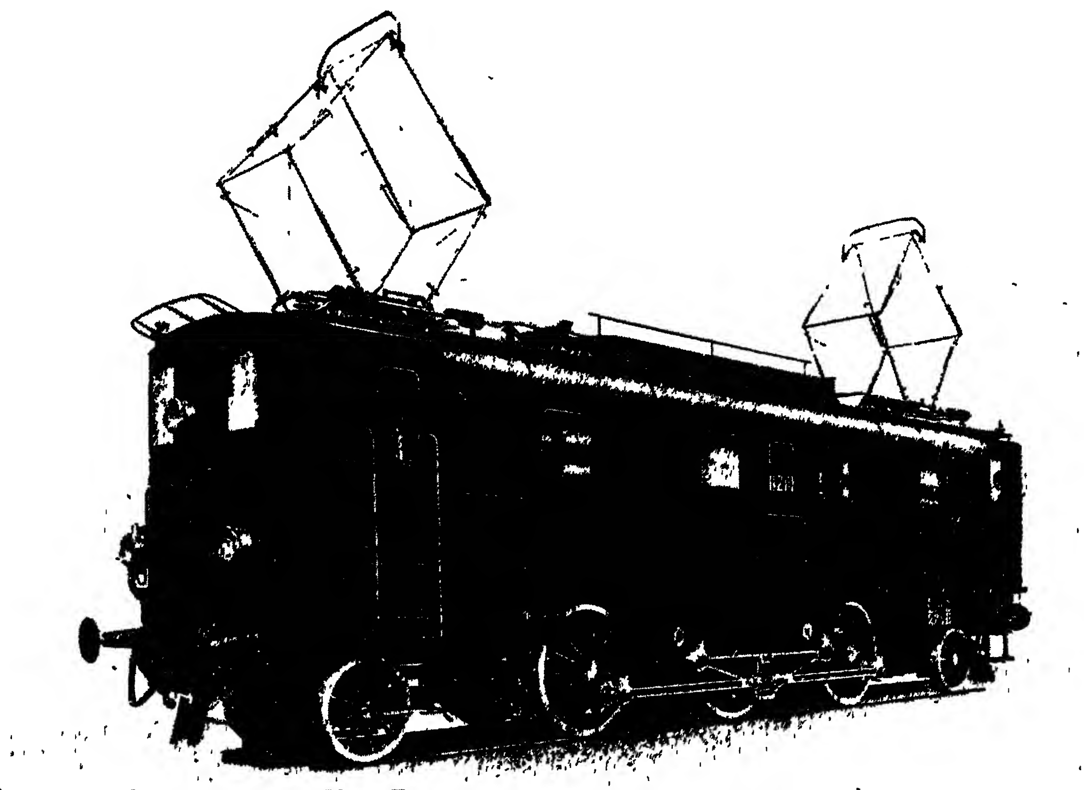
Three Coupled Drivers

As the classification indicates, the 2–6–2 locomotive comprises three coupled driving-axles with a carrying-axle at each end. The total wheel-base is 32 feet 9 inches; the fixed wheel-base is 15 feet 6 inches. Each carrying-axle has slight lateral play, as has also the central driving-axle, to permit the negotiation of the sharp curves.

The high-speed electric motors—of which there are two—are set side by side centrally in and across the locomotive frame. Transmission is through gearing; the reduction reads 2·84 to 1. The power from the motors is finally delivered to the driving-wheels through an inverted triangular connecting-rod system, the crank of the central driver engaging with the

apex of the triangle in a slide bearing. Particular attention has been devoted to minimizing the communication of all shocks and vibrations set up by the track to the which can be easily removed to allow of the motors or transformers being lifted out complete for overhaul or replacement.

On each side of the motion in the



THE OERLIKON 2-6-2 PASSENGER ELECTRIC LOCOMOTIVE.

It measures 44½ feet in length, weighs 91 tons, of which the electrical equipment represents 44½ tons, develops 1,650 horse-power, and can haul a train weighing 216 tons up a bank of 1 in 38 at 31¼ miles an hour.

power units; flexible couplings are introduced for this purpose. The design also permits the ready removal of the gear mechanism from the side when occasion so demands.

The locomotive cab, which is of the box-type, is divided into five separate sections or compartments. At the extreme ends are the foot-plates or driving-cabins. In the centre is the compartment housing the motors and other mechanism. This central section is flanked on either side by another cabin carrying the transformers and other incidental gear. The sides and roof of the cab are built of large sheet-steel panels, central compartment is a narrow gangway affording access to the mechanism from either foot-plate while the locomotive is running, and affording communication between the two driving-cabins. The roof may be readily reached by a folding ladder, but before this can be raised it is necessary to isolate the engine from the overhead electrical conductor for the safety of the workman or driver. Should the pantograph collector be in contact with the conductor when it is desired to ascend to the roof, and the preliminary lowering of the collector to interrupt the high-tension current have been overlooked, the very

THE TRANSALPINE EXPRESS, DRAWN BY THE BROWN-BOVERI ELECTRIC LOCOMOTIVE, LEAVING AIROLO STATION ON THE ST. GOTTHARD RAILWAY.

The main arteries through the Alps are rapidly being transformed, including the great trunk road extending from Lucerne to Chiasso in Italy by way of the St. Gotthard Tunnel. All the lines are to be electrified, and the day is not far distant when coal will be wholly banished from railway working in the country.

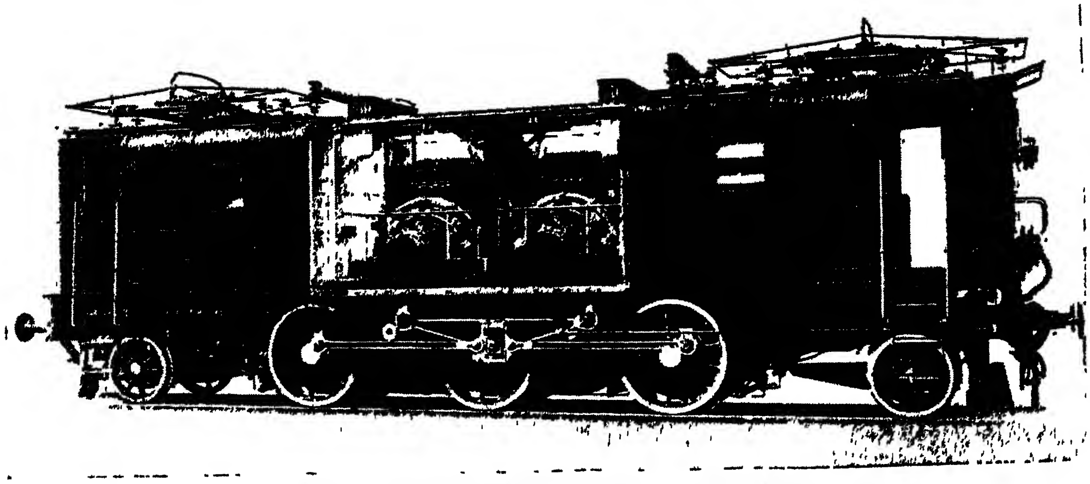
action of bringing the folding ladder into service rectifies the omission. It sets in motion the automatic pantograph lowering device, breaking the circuit, and thus allowing the roof to be gained in absolute safety.

Ample braking facilities are provided; these comprise the familiar Westinghouse and ordinary hand-braking devices respectively. The brakes can, of course, be operated from either end, and the total braking effort upon the wheels is equal to 80 per cent. of the total adhesion weight of the engine.

At the speed of 31·25 miles an hour each motor delivers 675 horse-power to the wheel rims and 825 horse-power under the 1½-hour rating; that is, 825 horse-power steadily for 1½ hours. The motors are of the Oerlikon compensated series type. The running direction of the engine is changed by reversing the current in the main exciting circuit by means of an electro-pneumatic commutator mounted above the motors. Speed variation is obtained through a system of contactors, normally actuated by an electro-pneumatic device, but by hand control in cases of emergency. In this manner twenty-three variations in speed in each direction are possible.

The locomotive is electrically lighted, special equipment having been installed therefor. It is also electrically heated, and when engaged in passenger service the attached carriages are also heated in this manner. By means of multiple control the engine can be employed as a helper upon a heavy grade or when an abnormal load has to be handled. In this instance the control is transferred wholly to the driver of the engine at the head of the train. By means of a special ampere meter he can vary and follow the effort exerted by the rear engine, thus relieving the driver of the latter from independent action, as is the case when working with steam-locomotives under such conditions.

The external lines of the 2–4–4–2 locomotive are somewhat different. As the classification indicates, there are two sets of driving-axles disposed in pairs in bogies, flexibly coupled together, and mounted in the single main frame. A carrying-axle is provided at each end. Two motors are mounted side by side in each bogie—four motors for the complete engine—but carried



THE ELECTRIC MOTOR COMPARTMENT OF THE OERLIKON 2-6-2 LOCOMOTIVE.
The sides and roof are fitted with movable steel panels to permit ready access to, and, if desired, complete removal of, the whole mechanism. This illustration shows the method of mounting the motors and reducing gear, as well as the coupling with the driving-wheels.

in a common cab, together with the attendant mechanism and cooling fan. The power from each pair of motors is transmitted through the Oerlikon gearing and triangular connecting-rod system to the pair of drivers carried in the bogie; the gear reduction in this instance reads 3·49 to 1. In essential details the equipment is similar to that of the 2–6–2 type.

The outstanding external difference in the cab is that at each end, forward of the foot-plate, there is a low compartment recalling the forepart and "bonnet" of the familiar motor-car. This is provided for the accommodation of the auxiliary gear, such as the air compressor and converter. As in the smaller electric locomotive, the sides and roof of the cab between the two driving cabs are built of sheet-steel panels to allow easy access to the motion. One divergence from the foregoing is the division of the hand-braking between the two bogies; there is separate control of each from both ends.

Auxiliary Gear Housing

The line electrical pressure, 15,000 or 7,500 volts, is stepped-down to the requirements of the motors by a single oil transformer set in the centre of the locomotive. Each of the two sections of the low-tension winding has eleven tappings with which, by the aid of the contactors, twenty-three variations in the forward and reverse speeds of the engine are provided. Each motor delivers 450 horse-power to the wheel rims under normal, and 500 horse-power under the 1½-hour, ratings respectively.

The two Oerlikon locomotives described have been designed essentially for passenger traffic; but the St. Gotthard line carries an immense volume of merchandise, and for this business another type of engine has been designed. The requirements of the two classes of haul are widely dissimilar, and the powerful Oerlikon goods engines of the 2–6–6–2 class have several points of interest.

The overall length, buffer to buffer, of the sixteen-wheeled freight electric is 63 feet 8 inches, extreme height 12 feet 4 inches, maximum width 9 feet 9 inches. The driving- and trailing-wheels are 53 inches and 36½ inches in diameter respectively. The mechanical part weighs 70·6 tons and the electrical equipment 56·4 tons; the total weight of the engine ready for the road is thus 127 tons, of which 104 tons are available for adhesion. At the normal speed of 22·5 miles per hour the motors develop 1,700 horse-power under continuous rating, 2,200 horse-power under the 1½-hour rating, and 2,520 horse-power for 15 minutes. At this speed the draw-bar pull under the continuous and 1½-hour ratings is 28,000 lb. and 38,400 lb. respectively; while the maximum draw-bar pull is between 48,000 and 52,000 lb.

Each bogie truck carries three coupled driving-axles and a carrying axle, the latter being mounted in a Bissel frame. The two bogies are of identical construction and consequently are interchangeable—an important feature from the maintenance point of view. The carrying- and central driving-axles of each bogie have a certain amount of side play for rounding the curves. Each bogie is fitted with two motors set side by side, and the power is transmitted to the driving-axles through the familiar Oerlikon gearing and side-rod system, with a gear reduction of 4·03 to 1.

Interchangeable Bogie Trucks

Externally, there is a conspicuous difference between this Oerlikon type used for goods or mixed duty and the express passenger locomotives. The cab in this instance is of the "steeple" type. It comprises a central cabin with a driving footplate at each end, set between two long, low, sloping bonnets, thus broadly dividing the body into three distinct sections. The motors and their incidental mechanism are carried under the bonnets, while the cab, in addition to the end driving positions, has

an intermediate compartment to accommodate the transformer and other details. In this example the analogy between the locomotive and the familiar automobile of conventional design is somewhat striking. The foot-plate may be said to coincide with the seat and dash-board of the road vehicle, with one half of the complete power installation—the unit for the one bogie—immediately in front of the driver. The arrangement imparts to the locomotive a distinctly rakish appearance, but ensures the driver a free and completely uninterrupted view of the track ahead, and brings the two foot-plates closer together. By projecting the ends of the roof slightly forward, complete protection against the penetration of snow and rain is provided for the drivers' cabins.

Hinged side and top doors to the bonnets of the motor sections facilitate inspection; while the provision of louvres to the top doors, controlled by an electro-pneumatic device, allow the air drawn in by the fans within for the cooling of the motors to be adjusted to requirements. Special arrangements are embodied to prevent the ingress of dust. The roof of the cab, and the high-tension apparatus fitted thereon, such as the pantograph current collectors, are reached by means of a short folding ladder, fitted with the automatic device to insulate the engine from the overhead conductor.

The driver, if necessary, is able to inspect the motors while the locomotive is running, by means of the special communication from the driving positions provided.

Inspection while Running

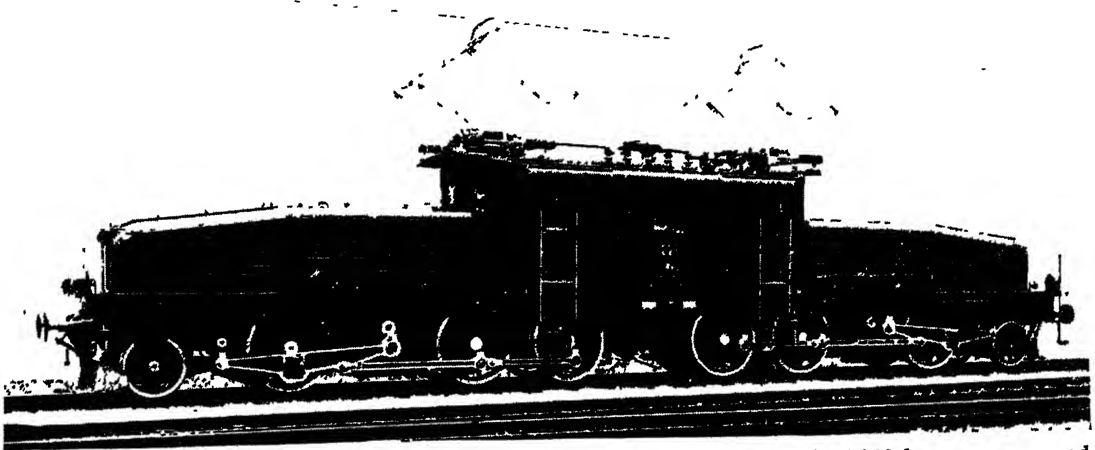
Immediately forward of each pair of motors forming a power unit is another small compartment containing the switching choking coil, two resistances for the auxiliary poles of the motors, brake choking coil, and air compressor. Upon the top of each pair of motors are mounted a cooling fan and the reversers. The step transformer, of the vertical core oil-cooled type, designed for a primary pressure of 15,000–7,500 volts, is housed in the compartment between the two foot-plates. It is of special design. A distinct feature is the direct discharge of the heat into the outer atmosphere through the roof of the cab. The cooling of the oil-tank is effected by forced draught through fans, which also ventilate the compartment.

Another characteristic of this locomotive is the elimination of the high-tension chamber. As a result, there is no danger of inadvertent contact with dangerous apparatus.

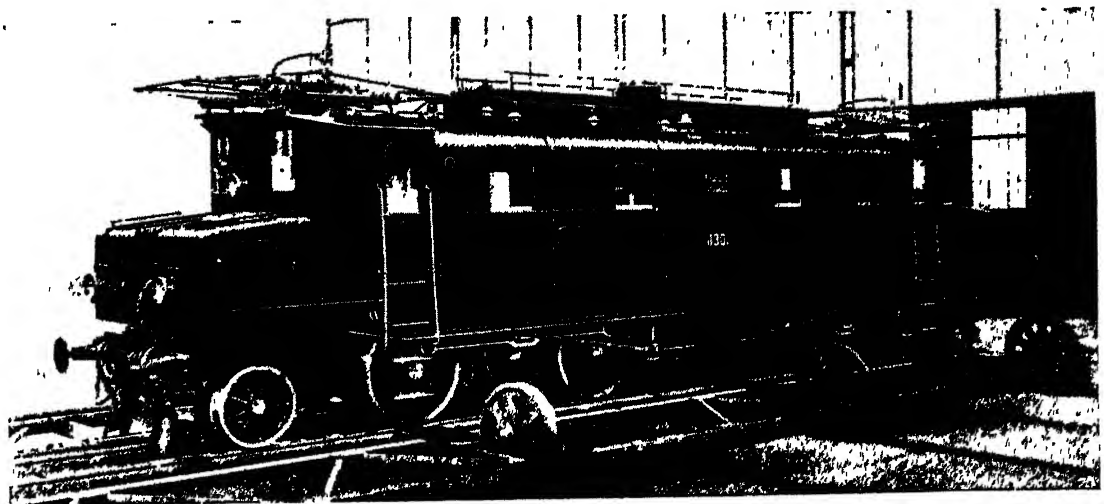
Interlocking Safety Device

The cover of the main oil-switch forms part of the cabin roof, while the earthing-switch is inside the oil-switch case. The possibility of the oil-switch tank being lowered while under line pressure is effectively overcome by an interlocking device with the pneumatic pantograph collector system, which ensures that the oil-switch tank shall be only lowered under conditions of no air pressure and closed earth-switch.

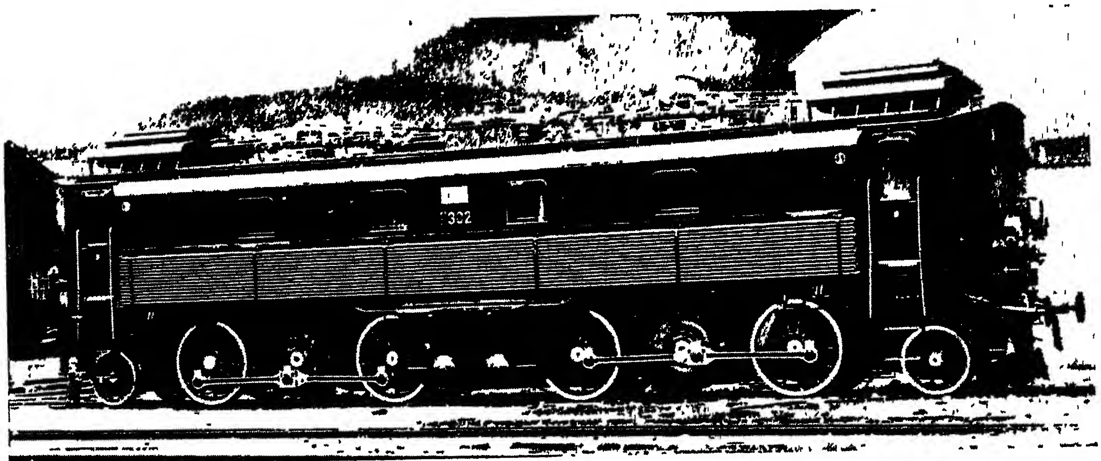
Either of the two pantograph current collectors mounted upon the roof is able to take full load at either 15,000 or 7,500 volts—the latter pressure is being used until steam traction is completely superseded—and the employment of compressed air assures the smooth and reliable working of these collectors under all temperature conditions, because the pressure of the bow against the line is kept practically constant at any variation in height between 15¼ and 23 feet above rail level. The collectors are raised and lowered by compressed air regulated by the control valve mounted in the driver's cab. Should there be an inadequate pressure of air—as, for instance, after the locomotive has been standing idle for an appreciable time—the driver can raise the collector by an auxiliary, manually operated air-pump; sufficient pressure to raise one collector to the line is



Powerful Oerlikon electric locomotive for goods traffic. Its normal rating is 1,700 horse-power, and it hauls a train of 860 tons over level tangent track at 22·5 miles per hour.



Oerlikon Electric locomotive, 2-4-4-2, for express passenger service. It measures 53 feet 1 inch overall, weighs 113 tons, develops 2,250 horse-power, has a maximum tractive effort of 32,600 lb., and hauls a train of 425 tons at 44½ miles an hour.



Brown-Boveri 2-4-4-2 express electric locomotive. It is fitted with four series motors, each developing 450 horse-power. To the side of the body is attached the novel radiator for cooling the oil of the transformers.

ELECTRIC LOCOMOTIVES OF THE ST. GOTTHARD RAILWAY.

forthcoming within thirty seconds. Once connexion is established with the overhead conductor, the power compressor can be set to work to raise the second collector in the usual manner.

The whole of the roof installation was subjected to a pressure test equal to four times that encountered during ordinary working, namely, 60,000 volts. This was applied, with all the usual earthed connexions in place, for ten consecutive thirty-second periods at five minutes' intervals. The locomotive is completed with electric or regenerative braking. Finally, it may be mentioned, this engine, in common with the 2–6–2 and 2–4–4–2 expresses, is fitted with facilities for the electric heating of the carriages when used in passenger service, or, should the train be equipped with its own steam-heating system, the engine supplies the necessary current for electrically heating the water in a special boiler installed for this purpose.

Brown-Boveri Electrics

Another important contribution to the electric working of the Lucerne-Chiasso line of the Swiss Federal Railways system has been made by the firm of Brown, Boveri and Company, of Baden (Switzerland). This company, which, by the way, was founded by a British engineer, was called upon to furnish a number of the twenty-four electric locomotives ordered by the administration for operation between Erstfeld and Bellinzona. This really represents the tunnel section of the St. Gotthard railway, and was the first stretch —about 70½ miles in length—to be taken in hand for conversion. The original intention was to build four locomotives of distinctive types, to permit searching experiments to be made, before carrying out the contract for the above-mentioned fleet of electrics, so that the outstanding features of design might be incorporated in the first section of standard locomotive equipment.

The outbreak of war urged the administration to put in hand the orders for the whole of the twenty-four locomotives without delay, to avoid the risk of the service having to be suspended or severely curtailed through lack of coal. To meet the critical situation, the Brown-Boveri Company undertook to build two types of locomotives, embodying the results of the experience gained with the experimental engines built by them for the Loetschberg railway. The two types are identical in all essential features.

Eliminating Road Shocks

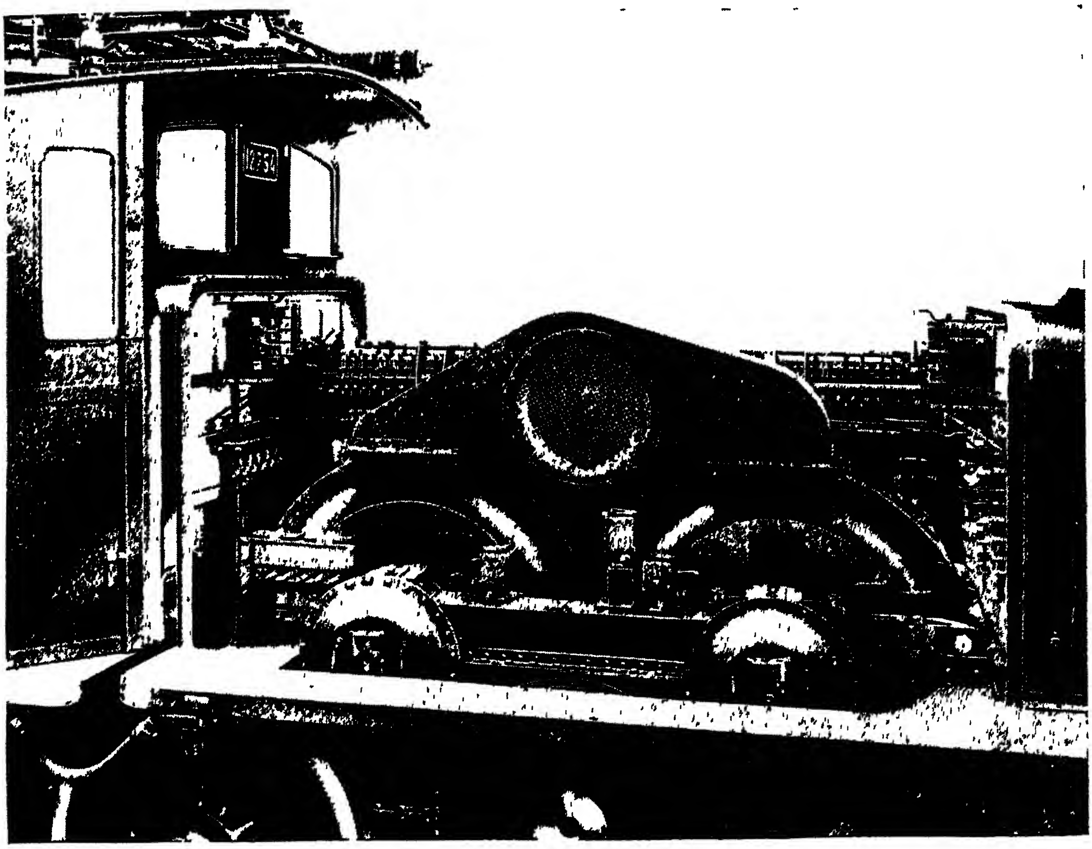
The locomotive belongs to the 2–4–4–2 class with cab of the box-type. It comprises two bogie trucks, each having two axles with coupled driving-wheels and two motors, and a carrying-axle at each end. The two bogies are flexibly connected to avoid transmission of road shocks to the main frame and to ensure easy riding round curves. The number of coupled axles was intentionally confined to two; the experience of the builders was that further increase in the number of coupled wheels tends to accentuate the vibration produced by the connecting rods.

The two motors are disposed in the bogie in the side by side manner generally adopted. The power is transmitted through toothed pinions mounted on each end of the armature shaft to a gear-wheel carried upon an intermediate shaft, and thence through the familiar side connecting-rod system to the cranks of the driving-wheels. The cab is of sheet steel, so attached to its frame as to allow easy access to the transmission system and the large gear-wheels upon the intermediate shafts. No electrical equipment, beyond the motors, is imposed upon the bogies.

As the motors are so set in their frame that they project through the floor of the cab, and are subject to appreciable displacement by the free riding of the truck about its pivot, openings of sufficient dimensions are provided to permit unrestricted move-

ment; but these openings have sliding plates which may be closed, so that in winter snow and ice cannot force their way into the cab through the floor. At each end of the cab is the foot-plate complete with all controls; the locomotive, as usual in electric practice, is operative from either end, thereby eliminating a visit to the turn-table. The braking equipment comprises the Westinghouse automatic air system with supplementary hand-brake acting upon all driving-wheels. The air necessary for the actuation of the brake, sanding device, whistles, and electrical apparatus is furnished by two Brown-Boveri compressors. The total weight of the passenger locomotive, ready for service, is 107·6 tons, while that of the goods engine is 121 tons. The whole of the mechanical part, as in the case of the Oerlikon engines, was manufactured at the Winterthur works of the Swiss Locomotive Company.

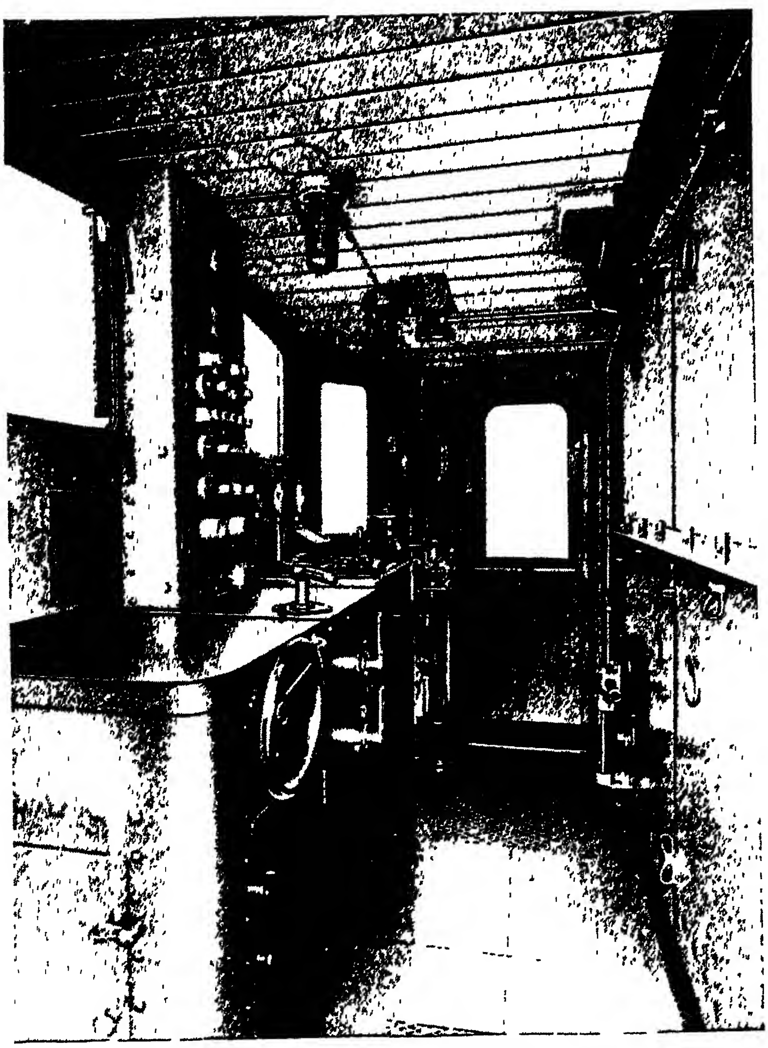
In so far as the electrical apparatus is concerned, the Brown-Boveri locomotives are of more than passing interest owing to certain features having been incorporated for the first time. For instance, all the main apparatus, control and operating devices, are combined with the transformers in such a manner as to form a complete unit which can be removed and introduced intact through an opening in the roof of the cab. This arrangement assures complete accessibility and at the same time permits the wiring to be reduced to the minimum. The whole of the high-tension apparatus is mounted within a grill—thereby preventing adventitious contact with



A POWER UNIT OF THE OERLIKON GOODS ELECTRIC LOCOMOTIVE.
Casing, or "bonnet," removed from one end of the locomotive to show the method of mounting the motors side by side.

the pre-eminently dangerous units of the installation—which cannot be entered while the collector is in contact with the overhead conductor.

An interesting feature is the novel radiator for the cooling of the oil for the transformers. Attached to the external surface of the cab on each side, and extending the full length thereof, is a nest of continuous piping, connected to a pump and the transformer. The oil is continuously forced through this radiator, which has an extensive cooling area presented to the outer atmosphere and the draught of air created by the movement of the train. The builders were induced to adopt the oil transformer in preference to the air type, which had hitherto found wide favour in this field, as the result of data acquired in the course of elaborate cooling investigations. The oil system in question is only slightly heavier than its air contemporary of comparative power, but from the point of security it is declared to be markedly superior. As the result, it has been found possible to instal only one transformer instead of two; the latter is the usual practice in the air system, one transformer being generally regarded as a reserve. The oil transformer of the locomotive in question, of 1,730 kilo-volt-ampere capacity, weighs, exclusive of the pump and external radiator, 27,500 lb., and measures 87 inches in length by 70 inches in width and 73 inches in height.



BEHIND THE POWER OF THE ELECTRIC LOCOMOTIVE
The "foot-plate" or driving-cab of the Oerlikon 2,520 horse-power freight locomotive, showing the various controls.

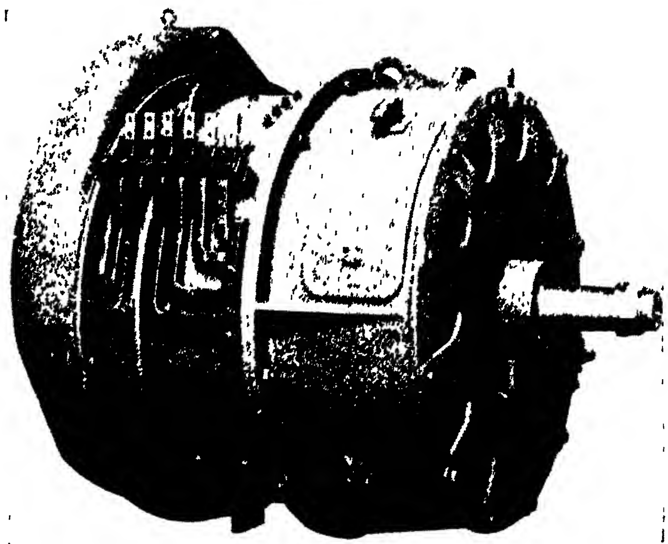
Current is collected from the overhead line by two independent pantograph collectors, to be led through the safety and other devices mounted upon the cab roof and the high-tension switch to the transformer, whence it is passed to the motors and finally to the rails which form the return. The high-tension switch of the two-step type, with resistance upon the first step, is placed on the roof of the cab.

The motors, connected in parallel and subdivided into two groups,

as already mentioned, are joined up in series. Ample ventilation is provided; the air drawn into the locomotive cab, after completing its work, is exhausted under the floor. The motors are of the Brown-Boveri compensated series type, with resistances introduced in such a manner as to ensure the rapid dissipation of the heat.

The current is led from the transformer, where it is stepped-down to the requirements of the motors through a "step-controller." Each side of this device corresponds to a group of motors; the steps of similar tension on either side are connected to corresponding tappings on the secondary winding of the transformer. Eighteen of these steps coincide with as many variations in the tension of the current; the lowest is 237 volts, and the highest 1,325 volts. Consequently, the tension difference between two successive steps is about 70 volts, or 35 volts for each pair of motors. The increment is not strictly uniform in regard to all the steps, but is constant so far as the conditions permit.

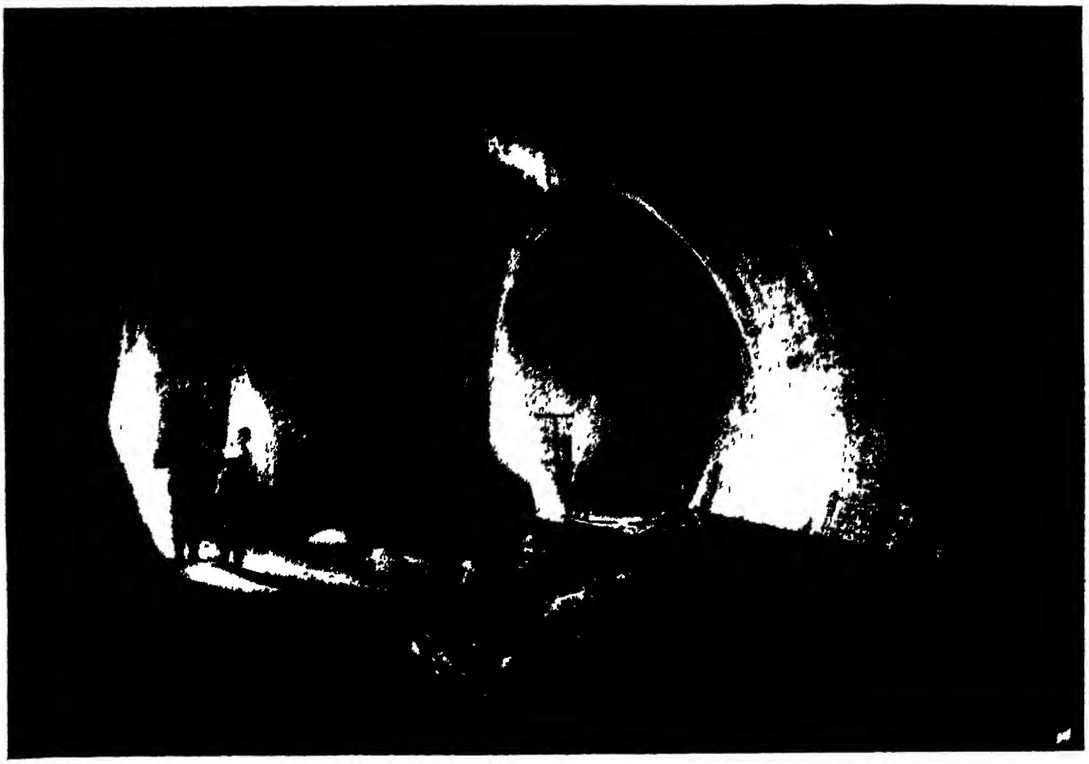
The arrangement possesses the advantage of simplicity. The current flowing from the transformer to the motors is induced to pass alternatively through the principal and auxiliary bars of the controller and its contactors with each variation in pressure by means of a brush bearing upon the contacts. Rupture of the current and short-circuiting of the transformer are prevented. The step-controller is operated by a continuous-current motor. A small converter, in conjunction with a battery of accumulators, is employed for this particular duty. The accumulator battery is regarded as a reserve or emergency device, permitting the operation of the foregoing apparatus as well as the illumination of the locomotive when the current from the line conductor overhead fails. This locomotive is also fitted with multiple control and regenerative braking.



BROWN-BOVERI 450-HORSE-POWER MOTOR OF THE 2-4-4-2 EXPRESS ELECTRIC.

Four of these single-phase series units are mounted in the locomotive, and furnish sufficient power to haul a train of 300 tons over a grade of 1 in 38 at speeds ranging from 20·8 to 31·25 miles per hour.

The electric locomotive designed for passenger duty is able to draw a train, weighing 300 tons, over a grade of 1 in 38 at speeds ranging from 20·8 to 31·25 miles per hour. The freight locomotive can haul a train of similar weight over the same grade at 31 miles per hour, and a 450-ton train at 20 miles an hour. In both instances, the locomotive, when starting upon an incline of 1 in 38 with a train of the prescribed weight, accelerates to the maximum speed set down within four minutes. In satisfying the above-mentioned requirements the engines develop 2,500 horse-power at the wheels, giving a tractive effort in the case of the passenger electric locomotive of 35,200 lb., and 48,400 lb. for that of the freight. The respective maximum speeds of the two types are approximately 47 and 40 miles per hour.



THE LARGEST TUNNEL IN THE WORLD.

Two conduits carrying the water from the wheel-pit and combined in a single bore 33 feet in diameter and 2,000 feet in length to discharge into the river behind the Horseshoe Fall. This photograph shows the junction of the turbine discharge tunnels with the main tail-race tunnel.

The Taming of the Niagara Falls—II

TRAPPING NATURE'S SPECTACULAR WASTE TO INAUGURATE INDUSTRIES OF STRIKING MAGNITUDE AND ECONOMIC IMPORTANCE

THE guiding principle of the third or Anglo-Canadian undertaking was the perfection of ways and means to bring the turbines to the water, rather than to lead the water to the turbines, as had been the practice with the previous hydro-electric schemes at Niagara. Having succeeded in this part of the task the engineer was now confronted with the problem of carrying the water, upon the completion of its designed duty, away from the turbines. He might have emulated the practice adopted by the Niagara Falls Power Company by cutting a tunnel across the elbow formed by the course of the river, to discharge the spent water through the cliff-face into the Whirlpool Rapids below; but he decided to cut his way through the rock down the river to gain an outlet for his tunnel behind the Horseshoe Fall itself, and thus discharge the turbine water into the cataract.

This proposition for the disposal of the waste water was severely assailed. Nothing

certain was known of the geological formation of the cliff behind the Fall. It might be vertical or concave; it might be solid rock or a pile of loose debris. It was known that the crest was receding gradually through the water filing away the rock at the rate of about 2½ feet a year.

When it was realized that the engineer was not to be turned from his purpose, another line of contentious argument was assumed. Granted that the tunnel could be driven, would the back pressure of air and water dam the discharge from the tail race? Was the falling water a compact defined sheet, and did it pour over the ledge in the solid stream assumed by milk when poured out of a jug? Or was the rear face of the sheet torn by contact with jagged projections from the cliff face? If the sheet of water were broken up in such a manner behind, then the tunnel must assuredly become charged with water exerting an enormous back pressure. Apart from such possible water trouble, the critics averred that the wind pressure would probably be sufficient to hold up the water.

Problems of the Falls

Unperturbed, the engineer constructed the tunnel as he had proposed. Beneath the turbines there are two tunnels, driven parallel with the wheel-pit and on each side of the latter. The turbines eject the spent water alternately right and left; that is to say, No. 1 turbine discharges into the right-hand tunnel; No. 2 turbine delivers its water into the left-hand tunnel; No. 3 turbine into the right-hand tunnel; No. 4 turbine into the left-hand tunnel; and so on upon either side in turn. If repairs to the right-hand tunnel become necessary, all the turbines discharging into that tail-race can be shut off, and the tunnel emptied to permit of access; in that event, the turbines ejecting into the left-hand tunnel continue at work. The second tunnel can be isolated and penetrated similarly when desired, by shutting off the turbines ejecting into that tail-race.

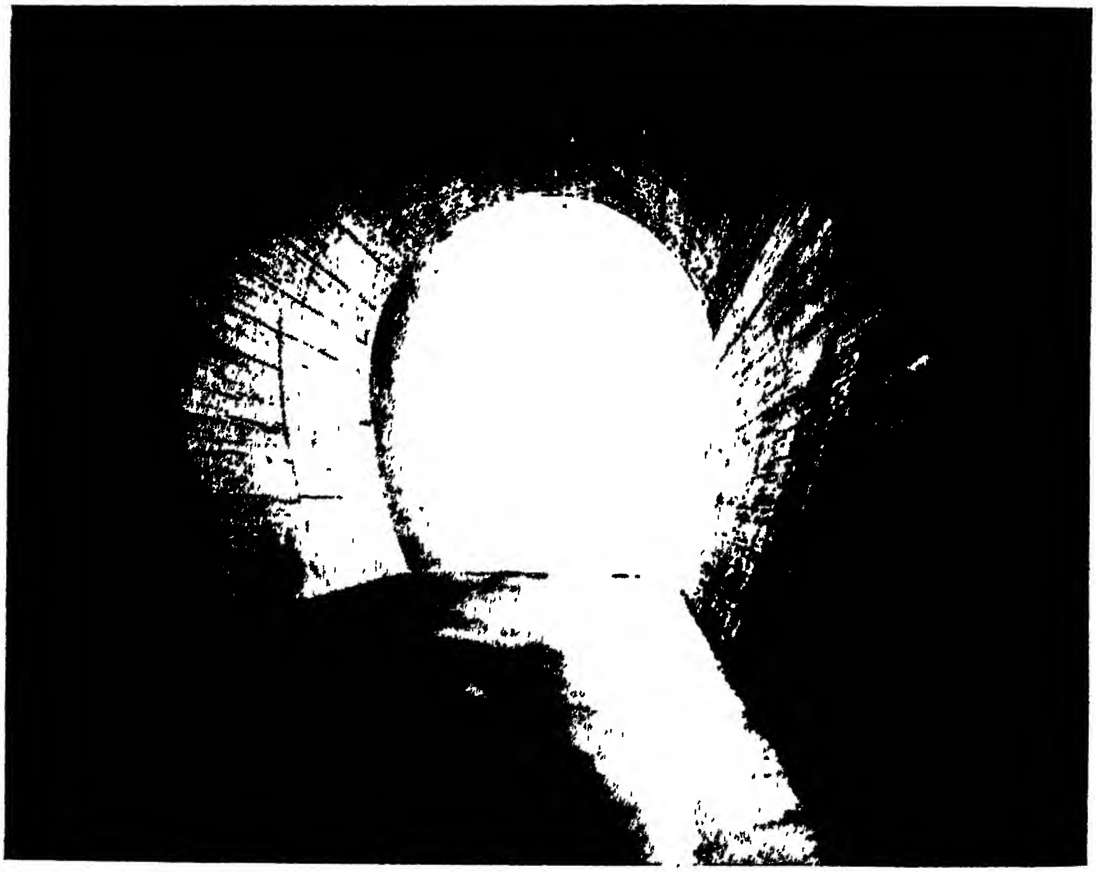
Beyond the northern end of the wheel-pit under the lower end of the power-house, these tunnels converge to empty into the main tail-race tunnel, carrying away the whole of the discharge. It must be pointed out that the wheel-pit has no connexion with the tunnel flanking it on either side. The turbines eject direct into their designed escape tunnel through individual draft-tubes. When one-half of the plant is shut down to permit inspection of a tunnel, the latter drains completely; no water can back into it, and flooding of the plant is impossible. At the north end of the wheel-pit provision is made for a thrilling voyage of discovery. There are iron doors permitting passage to a point whence, looking down, one may see the water ripping through the two tunnels on its way to enter the main discharge. When one-half of the battery of turbines is shut off one may descend into the dry tunnel, and, passing along, gaze upwards into the yawning vents from each of the turbines. It is an eerie sensation. One can hear the muffled roar of the water pouring through the other tunnel a few feet away, and feel the tremor of the water in its thunderous passage; the roar grows in intensity as the confluence of the two tunnels is approached; at the main discharge bore the din of crashing and scurrying water is deafening.

The main tail-race tunnel is the most imposing section of the whole work. It has a diameter of no less than 33 feet, a length of 2,000 feet, and a steady downward slope. This tunnel was not driven from the wheel-pit end, but from another point lower down the river. On the bank a shaft was sunk to the depth of the main bore. From this point a drift was driven straight across the river for 700 feet to the point of intersection with the line of the tail-race tunnel; thence the tunnel borers crept yard by yard upstream, some 200 feet under the thundering river above, towards the wheel-pit

The Main Tail-race Tunnel

tunnels. The debris, as it was brought down by drill and explosive, was loaded into cars and shot into the river through a narrow shaft driven off the construction tunnel for this special purpose.

Cautiously, since no one knew precisely what would happen when the final breach was made, the tools were set to work to make an opening in the top of the drift. The final explosive charge was fired. The



WHERE THE HARNESSED WATER REJOINS THE NIAGARA RIVER

The mouth of the main discharge tunnel; the white mass is the inner face of the Horseshoe Fall, 90 feet below the ledge over which the river tumbles. Driving this tunnel to return the water to the river behind the Fall was one of the most startling features of the scheme of the Electrical Development Company to draw electricity from this wonderful cataract.

When the tunnel builders had crawled up-stream for about 1,000 feet it was decided to break through the wall of rock between the junction of the main and construction bores and the Falls. By driving the lower section in this way it would be easier to dump the excavated material into the river itself. A drift was driven in this direction until at last there was only a thin sheet of rock between the men in the tunnel and the tumbling water outside, the roar of which was plainly audible.

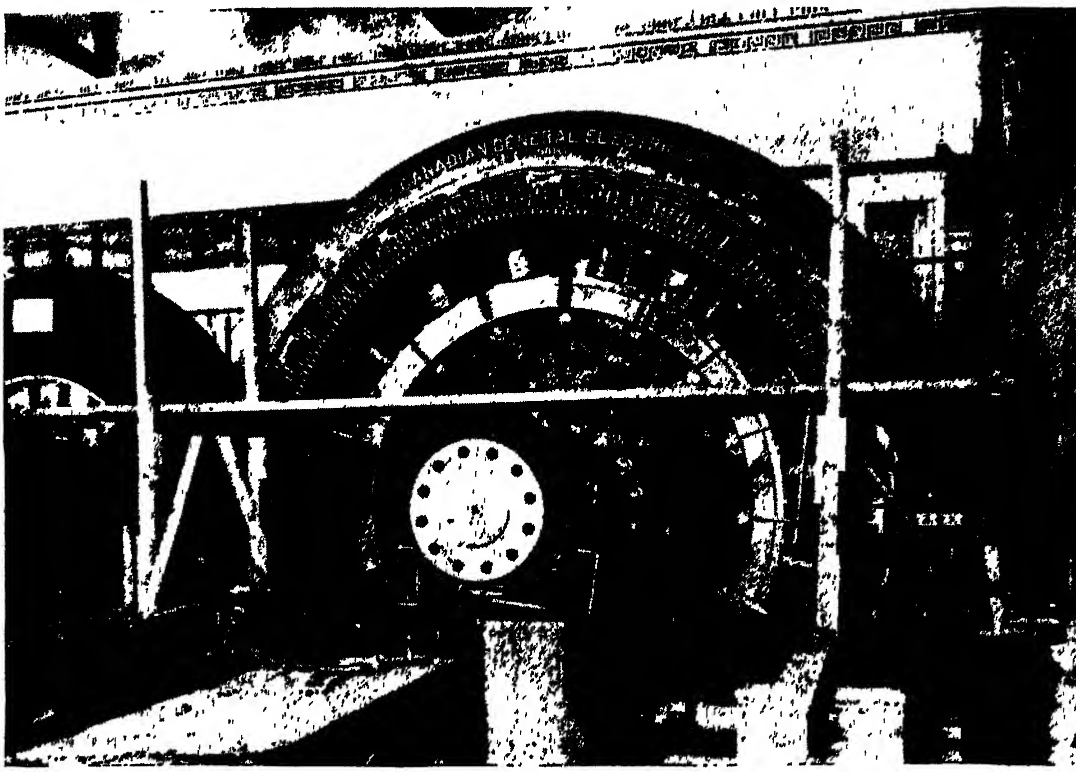
veil of rock came tumbling down; an instant later the bore was charged with dense clouds of spray and a nerve-wracking din; water began to rise and the workmen scampered madly back to safety.

What was the cause of the inundation? It seemed that the critics were right after all. The engineer, determined to fathom it, crawled gingerly to the small opening in the drift and looked out through the breach in the sheet of water upon the Horseshoe Fall from behind—a point whence it had

never been seen before. He observed that the tunnel vent, designed to be near the bottom of the precipice, was forced to penetrate a huge mound of talus—debris worn away by the water at the crest, and thrown against the toe of the cliff—which curved over him like a huge arch.

Having fathomed the cause of the inundation, the engineer decided to blow the accumulation of broken rock outwards and clear of the tunnel mouth. The experienced tunnel makers had to proceed warily forward through the blinding spray and deep water, and stand in a drenching downpour while they plied their drills and laid their explosives. Shot after shot was fired, but no visible impression was made; obviously the obstruction could not be cleared from within.

The engineer-in-charge, with two volunteers, decided upon an extremely hazardous enterprise. The three men roped themselves together, and, equipped like mountaineers, worked their way through the drift, wormed through the opening, and thus gained the toe of the cliff screened from the outer world by the huge sheet of falling water. Their foothold was precarious; while one man anchored himself to resist the storm of wind and water, the others groped about the pile of debris. The tunnel had driven plump into a miniature mountain of the broken rock—one of those instances of bad luck which the engineer encounters when engaged upon ambitious schemes. There was only one way of removing the obstruction—by dynamite applied from outside.



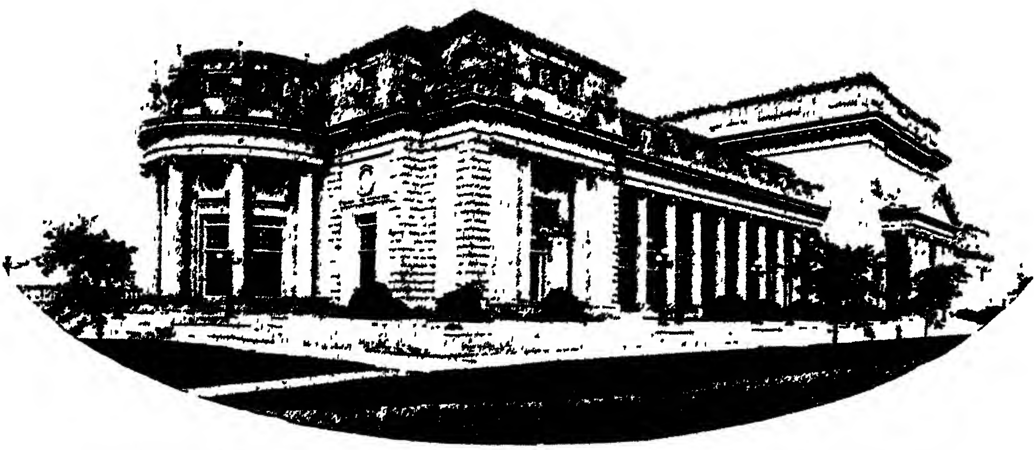
THE LARGEST CANADIAN GENERATING UNIT AT NIAGARA FALLS

One of the two 15,000-kilo-volt-ampere generators installed in the extension to the Ontario Power Company's station. It is driven by a 20,000- to 25,000-horse-power turbine.

Then commenced a spell of tedious toil. Time after time, the three adventurers made their hazardous journey bearing with them a small quantity of dynamite. More than

once they were swept off their feet. At times they were knocked to the ground by the falling torrents of water; but the pile of dynamite gradually accumulated at the spot desired by the engineer. At last, upon retreating into the tunnel, a thin trail of wire was uncoiled behind the trio. From a safe distance the exploder was sharply rammed home. A terrifying roar followed, and the bore was filled with smoke, fumes, mist and dust. The wind quickly dispersed the effects of the explosion, and a shaft of diffused daylight illumined the bore; the obstructing hillock of talus had been blown into the whirlpool below. The water which had been hurled into the tunnel raced madly to the vent, and within a few minutes the bore was completely empty. Afterwards the tunnel proved too dry to supply enough seepage for the working of the air-drills.

The tunnel is lined with brick from end to end. At the vent behind the curtain of water one stands 140 feet below the crest of the precipice which leans some distance forward, owing to the water having worn the cliff away to the form of a springing arch. Looking outwards one sees daylight through the thick veil of water formed by the Horseshoe Fall, which gives a diffused illumination as through a huge sheet of ground glass. When the turbines are running at full pressure, the spent water ejected from the bore impinges upon, and mingles with, the Fall itself. As the crest is being worn away at the rate of 30 inches a year, it is essential for the tunnel to recede simultaneously. The outer extremity of the tunnel is of concrete; the rock above, broken away by the water in falling, strikes the tunnel portal, and in this way gradually pares down its length. Had the tunnel been of sufficient strength it would have projected itself through the Fall by this time, because the crest has receded by about 40 feet since the bore was completed.



THE HANDSOME POWER-STATION OF THE ELECTRICAL DEVELOPMENT COMPANY
The whole installation connected with this power-house—which stands upon land reclaimed from the bed of the Upper Rapids—was purchased by the Hydro-Electric Commission for about £6,500,000.

The water flowing into the forebay, and through the arches and racks, enters the steel penstocks, 10 feet 6 inches in diameter. At the head of each is fitted an electrically-operated gate, which controls the flow of the water before it makes its sensational sheer vertical drop of 140 feet to play upon the wheels of the turbines. The falling column of water is divided into two streams so as to enter the turbine from above and below. In this way the upward thrust exerted by the rising water is calculated so exactly as to

carry the enormous weight imposed. Consequently, the turbine, with its vertical shaft extending into the power-house above, practically floats in the water which furnishes the motive power. In addition, there is the massive bearing mounted upon each of the three flying arches in the wheel-pit, which is lubricated by oil under a steady pressure of 350 lb. per square inch; this bearing is capable of supporting the entire weight of the revolving parts should the water thrust fail.

Above the wheel-pit is the imposing power-house—one of the most handsome ever designed for the purpose — 500 feet in length by 70 feet in height, built of Indiana limestone in the Italian Renaissance style. The generators, coupled to their respective turbines by the vertical shaft, are disposed in a single row down the centre of the lofty hall. Each machine delivers three-phase 25-cycle alternating current at 12,000 volts. Seven of these units, connected to 15,000-horse-power turbines, are of 10,000 kilowatts each; while the other four, coupled to 13,000-horse-power turbines, have an individual rating of 8,000 kilowatts.

A Handsome Building

Each generator has its own exciter mounted on the end of the generator shaft; while, also underground, are two large exciting units, each of 500 kilowatts, directly connected to Pelton wheels. The power-house also carries the auxiliary equipment, except the transformers, which are accommodated in another building overlooking the Falls and where the current is raised to a pressure of 60,000 volts for transmission to Toronto and other centres.

Upon the completion of the power-house the engineer raised the siege which he had been maintaining against Nature's hydraulic forces. The coffer-dam was demolished, and the Rapids, which had been held at bay for three years, were allowed to boil and seethe once more upon their old ground, except the part that had been permanently reclaimed. With the return of the water the wing-dam was submerged, as were also the arches. The water level is within about 5 feet of the parapet crowning the wall that flanks the power-station; while, at the north end, the water rolls over the spillway in a miniature cascade on its way to the Fall below.

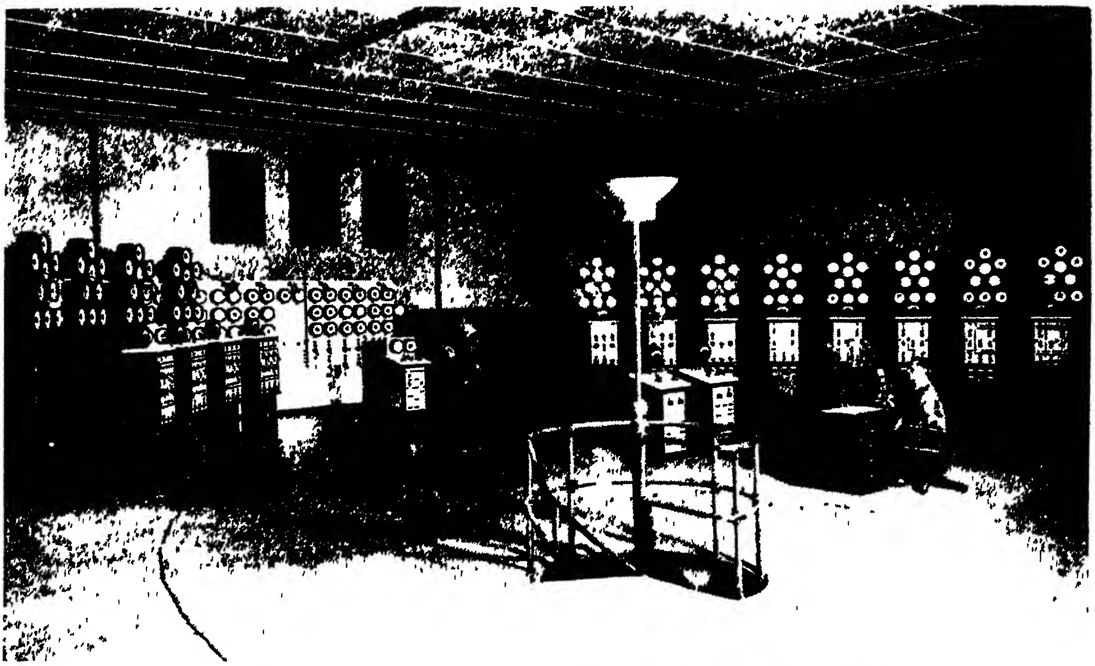
Had the hydro-electrical conquest of Niagara been continued on the foregoing scale, it is probable that by now the banks on each side would have been dotted with power-stations. About twenty different projects for utilizing the water were advanced as far as the paper stage, and many would doubtless have fructified but for one effective check. The Burton Act, to which reference has already been made on pp. 23-24, was in operation. It was supplemented by a deliberation between the United States and Canadian Governments to determine exactly how much water should be set aside for electric generating purposes. As the greater volume of water favoured the Canadian Fall it was settled that no more than 36,000 cubic feet per second should be taken on this side, and no more than 18,500 cubic feet per second upon the American side.

Seeing that electric energy to the extent of 160,000 horse-power was being exported from the Canadian power-houses to the United States, which was equivalent to a flow of 12,000 cubic feet of water per second, it will be realized that Canada's advantage was not so pronounced as it appeared at first sight. The Dominion Government, however, retains the right to cancel these current export contracts, but they have been honoured to this day, and the export will undoubtedly continue until such time as developments of industry upon the Canadian side demand a revocation to satisfy domestic exigencies.

Power Exported

During later years another force has arisen to prevent the exploitation of Niagara's power to private advantage. This

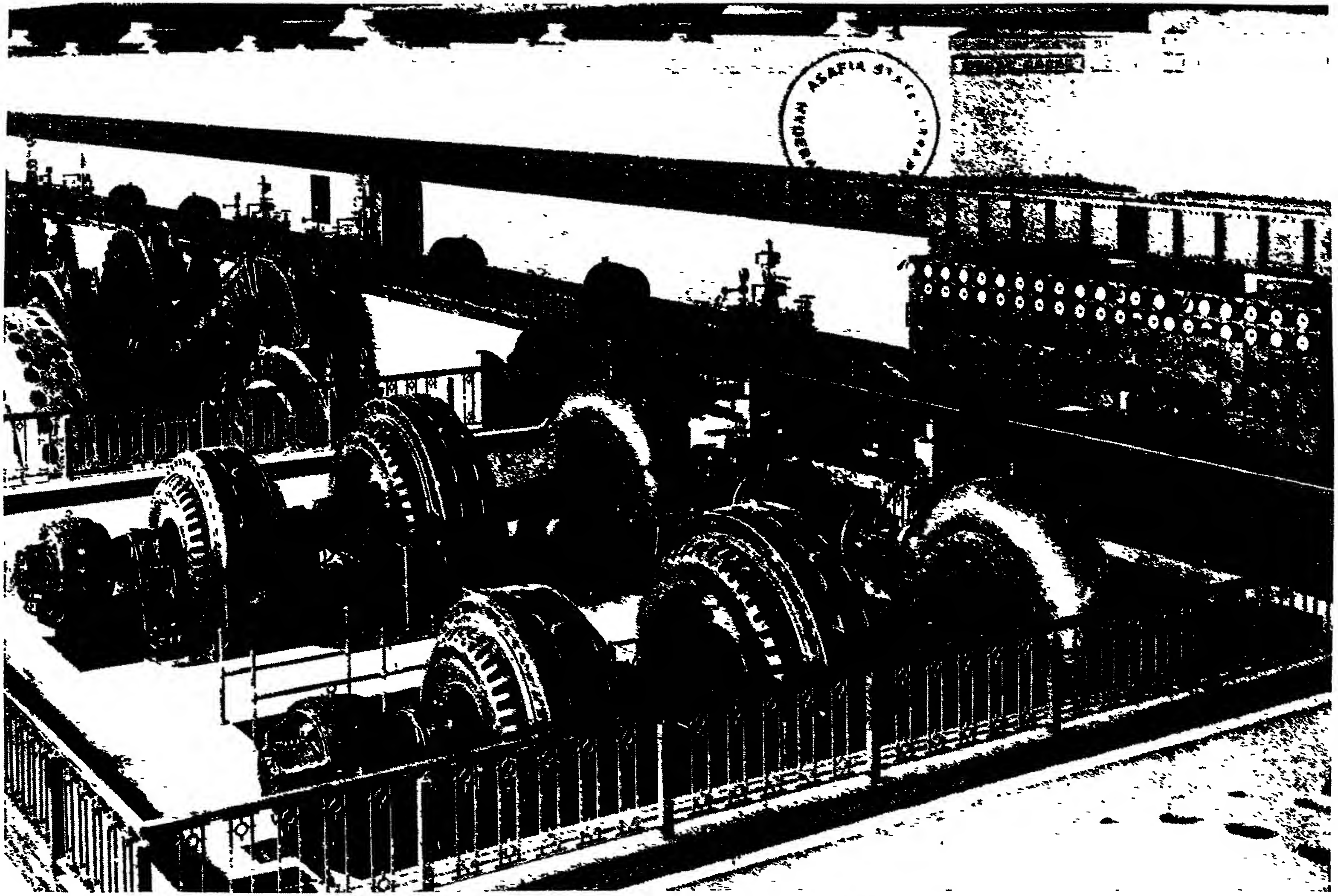
is the Hydro-Electric Power Commission of Ontario, a quasi-government organization invested with full powers to nationalize the hydro-electric generating facilities upon the Canadian shore. This was brought about by the activity of various municipalities, who came to the conclusion that they were being unfairly exploited by the private undertakings already established. The Commission was formed in the first instance to purchase power in bulk, and to distribute it, virtually at cost price, to the consumers; but with the passage of years it advanced from the wholesale purchasing to the manufacturing status, and to-day is in virtual control of the hydro-electric situation at the Niagara Falls so far as Canada is concerned.



CONTROL ROOM OF THE ONTARIO POWER COMPANY AT NIAGARA FALLS.
Here some 238,000 horse-power of electricity is held in leash. The operation of the station is controlled by the "dispatcher" seated at the desk, with its telephone switch-board.

The first project of the Commission was to make a contract with the Ontario Power Company for the supply of 100,000 horse-power of electricity in one block. This scheme proved successful, but eventuated in the Commission buying the private company outright. It then turned its attention to the Electrical Development Company, from which it purchased power in bulk to the extent of 25,000 horse-power until the expiration of the contract. It then set out to acquire this undertaking, and in December, 1920, as the result of two years' negotiations, the Toronto Power Company and its subsidiaries were purchased by the Hydro-Electric Power Commission and the City of Toronto for a sum of about £6,500,000. By these two deals the public has secured complete hold of 381,000 horse-power of the total of nearly 500,000 horse-power being produced at Niagara.

Yet the public assertion of its rights has not brought about any diminution in the activity with which Niagara is being tamed. Indeed, developments are being pursued with accentuated vigour. One of the first projects of the Hydro-Electric Commission upon the acquisition of the Ontario Power Company, was to increase the output of



EXCITER BAY OF THE GENERATING STATION OF THE ONTARIO POWER COMPANY AT NIAGARA FALLS.

This installation comprises two 1,600-horse-power turbines, 14 three-phase 2,300-volt motors, 4 generators of 40 kilowatts each, and 10 generators of 60 kilowatts each, which would be able to satisfy the electric lighting requirements of a large town.

this undertaking by adding a new bay to the station, which involved the construction of a third conduit between the headworks and the power-house. The third water conductor, 6,700 feet in length, built of wood staves, is 13 feet 6 inches in diameter, similarly buried in a trench, and feeds two steel penstocks, 216 feet in length, carried through tunnels driven through the solid rock. Each delivers water to a turbine developing 20,000 horse-power under a head of 180 feet, coupled to a 15,000-kilo-volt-ampere generator delivering 12,000-volt three-phase 25-cycle alternating current at 187·5 revolutions per minute. By the provision of these two new units the output of the station is increased to 238,600 brake-horse-power. This extension was assumed essentially as an emergency measure to meet the increased demand for power until the new enterprise, known as the Queenston-Chippewa Development, is completed, which will have an ultimate output of about 500,000 horse-power.

Floating Ice a Menace

It has been stated elsewhere that the salient characteristic of the Niagara River is its striking constancy, and that it is only perverse winds which exercise any effect upon this aspect. In carrying out the above-mentioned extension these influences had to be seriously considered. The circumstance that unfavourable winds must not be ignored was brought home very forcibly during the winter and spring of 1909. For three days, February 14th, 15th and 16th, an east wind blew up Lake Erie, so continuously driving the water before it that the volume of water discharged into the Niagara River became reduced to such a level as to create a situation without parallel since March, 1848. Floating ice collected and settled in the Upper Rapids, with the result that the supply of water flowing to the south of Goat Island was shut off. Only here and there an insignificant rill of water dropped lazily over on the American side. The famous cliff, indeed, was high and dry.

On the Canadian side, despite the fact that the normal American flow was diverted into the Horseshoe channel, only about one-half the usual quantity of water was discharged over the ledge. The power-generating companies on each bank could not maintain their output. On February 17th, the wind swung round to permit the resumption of the normal flow, but so slowly that several days passed before the American and Horseshoe Falls regained their familiar appearance.

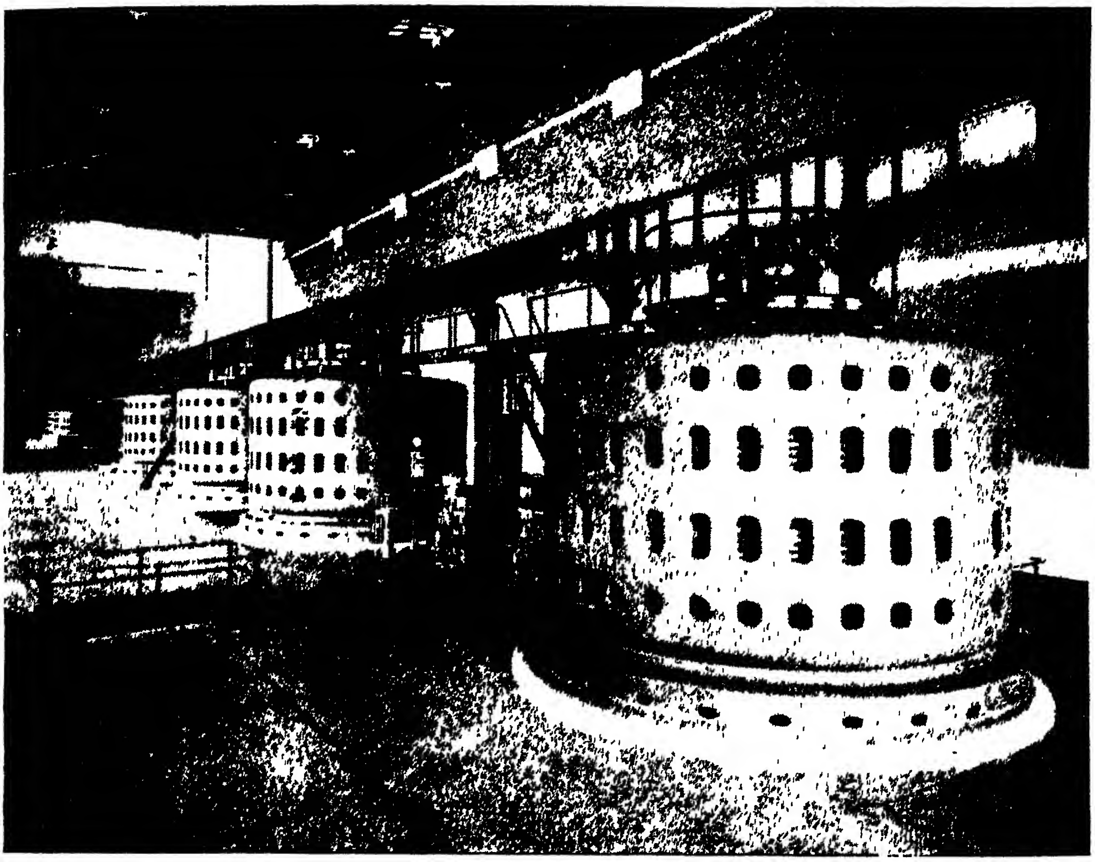
Hurricane Aids the Ice

But the worst was not over. Some weeks later, on April 7th, a terrific hurricane swept over Lake Erie from the west, and hurled the breaking ice into the Niagara River—much more than it could comfortably carry. It was a magnificent procession of stately floes which was borne swiftly to both cliffs by the hundreds of tons per second, to fall in terrifying noise. The wind not only impelled the ice forward in huge fields, but sent the water scurrying down the channel with greater speed and in greater volume than had been recorded before.

But the ice constituted the greatest menace. When it was hurled into the lower gorge to be whipped about in the Whirlpool, it could not get away quickly enough to allow the water to gain Lake Ontario. A gigantic barrage was formed; within two days the level of the lower river, which is normally 343 feet above sea-level, had been lifted 40 feet. The engineers in the Ontario Power-House by the waterside had been following the persistent rise of the water with the gravest apprehensions, and had taken every human precaution to avert the inundation which was inevitable, unless the ice gave way. During the night of April 9th, the engineers were driven from their position. The river burst in through the windows in huge cascades, bearing with it masses of ice which

were flung hither and thither among the machinery. The electric generators were partially submerged, and the whole installation had to be shut down.

masses. The pressure against the abutments of the huge steel bridge at the Falls was being raised to a dangerous degree; while the mass was lifted to within 15 feet



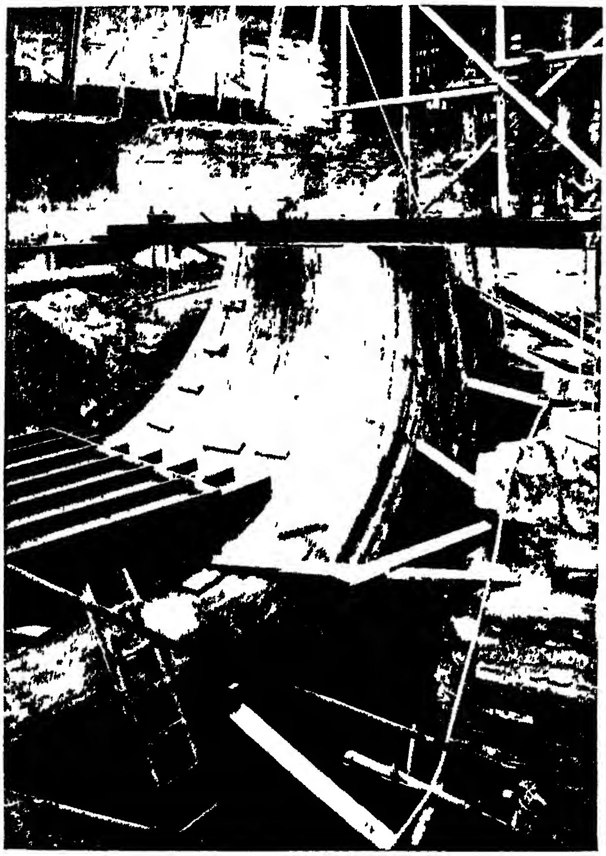
DRAWING 102,000 KILOWATTS FROM THE NIAGARA FALLS.
Interior of the generating station of the Electrical Development Company, showing the battery of 11 vertical generators coupled direct to the turbines placed in the wheel-pit 170 feet below.

The gorge was jammed with ice from near the foot of the Falls to the outlet to Lake Ontario. The only open spot was the Whirlpool Rapids. The sport of the water flowing beneath and forcing the ice upwards to pile it into a gigantic straggling barricade 40 to 50 feet in height, produced a deafening noise. So terrific was the upheaval that the electric railway which runs through the gorge for several miles was submerged by banking ice to a depth of from 10 to 20 feet.

The jam was now regarded with alarm. Boat-houses, docks, hotels, and other structures lining the waterway were being inexorably ground to pieces by the ever-moving of the deck of the Lewiston Suspension Bridge which normally is 65 feet above the water. As the outlet to Lake Ontario was completely blocked by a wall of ice, 50 or more feet above usual water-level, blasting measures had to be taken. On the 22nd of the month, an attempt to breach the barrage at Fort Niagara was launched. Hour after hour heavy charges of dynamite were fired, but the effect upon such a peculiar material as ice was relatively insignificant. After some twenty-four hours of continuous blasting work, the water-level was seen to be receding and the ice to fall with it. Once an impressive breach was made the current

and force of the imprisoned water did the rest; by Sunday the waterway had been restored to its normal level.

Large gangs of men were impressed to shovel out the hundreds of tons of ice which had been deposited upon the floor of the Ontario Power-House; the drying out of the generators was found to be a task of considerable magnitude. The estimated damage approximated £20,000, without including the loss of revenue through the suspension of supply, or the value of the lubricating oil carried by the bearings, the normal supply of which is the contents of 100 barrels.



THE DISCHARGE FROM THE 20.000 TO 25.000-HORSE-POWER TURBINE.
The mould for the draft tube, leading from the water-wheel to the river outside, ready for the concrete.

The sudden suspension of the supply of 149,000 kilo-volt-amperes of energy was felt throughout a zone of 100 miles or more. The other Canadian power companies rendered valuable help by running their plants to the uttermost degree of safe overload in their endeavours to take up the duty for the Canadian consumers.

On the American side the situation was more alarming, since none of the power ordinarily exported from this station was now forthcoming. A 10,000 - horse - power gas - engine belonging to the Lackawanna Steel Company was turned over to supply current for the operation of the Buffalo and Hamburg Electric Railway and other consumers as far away as Rochester.

Accordingly, when the new bay was added to the Ontario power-station, the engineers of the Hydro-Electric Power Commission decided to take every precaution to avert a repetition of the disaster of 1909 in so far as the two new 20,000-horse-power units were concerned. The sills of the windows of the original station, which had proved the vulnerable point, had been raised, but the sills of the windows of the new bay were set at a still higher level. The power-house is also entered at the lower end by a standard-gauge railway track which necessitated the provision of a portal with a relatively low sill, but this apparently weak spot is strengthened by the provision of facilities for the prompt insertion of stop-logs to dispute the water in times of abnormal flood. The outer wall of the building takes the form of a cantilever to resist a 40-feet head of water in the event of a rise to a flood-level of 50 feet.

Although the year 1909 is memorable in the annals of this station it was exceeded by the conditions experienced during the winter of 1917-18. When the demand for power for the manufacture of munitions was at its highest, it was found necessary

AIR FOR COOLING THE HUGE GENERATORS.
Chamber and intake of ventilating blowers, which are direct-coupled to 35-horse-power motors.

to run the station at the safe maximum overload level continuously. The power-house was not ravaged by flood, but, owing to the ice conditions, output had to be reduced for short periods. For three months the total output of the various plants was reduced by no less than 20,000 horse-power, owing to the failure of two generators of the Canadian Niagara Company's plant. These had scarcely been restored to service when another failure, curtailing output by 10,000 horse-power for another month, occurred. Ice and pressure imposed upon supply were responsible for these exasperating incidents. During summer and autumn, an average supply of 50,000 horse-power was maintained.

A feature of the auxiliary equipment installed in the new wing of the Ontario Power Company's station is the provision for the adequate cooling of the new immense 15,000-kilo-volt-ampere generators. To enable each machine to carry its rated load within the specified rise in temperature, it is necessary to drive 60,000 cubic feet of air every minute through the ventilating ducts in the armature. To secure this supply, which is drawn from the outer atmosphere, ducts are provided in the solid concrete wall of the façade of the building, and at a point well above the highest recorded flood water-level. These channels extend downward to deliver the air into a common chamber placed beneath the railway track extending through the building. The air is drawn through these ducts into the air-chamber by four blower units of 60,000 cubic feet capacity a minute, and is discharged directly into the pits carrying the generators. Each of these blowers, placed between the air-chamber and the pits, is driven by a direct-connected 35-horse-power induction motor. One blower unit is used normally; the others serve as a stand-by. A ventilating monitor, 22 feet by 4½ feet, placed in the roof directly over each generator, expels the heated air from the building.

The industrial transformation at Niagara is phenomenal. Upon the American side, when projects have been completed, 500,000 horse-power of electrical energy will be forthcoming. Consolidation of the companies exploiting the resources upon the American side of the Falls has facilitated this notable development, and during 1921 the output was swelled by the completion of an increment of 120,000 horse-power. Three hydraulic turbo-generator units, ranking as the largest placed in service up to this time, and exceeded by only a few steam-turbine driven combinations, were

DELIVERING 60 000 CUBIC FEET OF COOLING AIR PER MINUTE
The continuously maintained stream of cold air is carried to and forced through the ventilating ducts in the armature of the generator.

set in position. Each of the I. P. Morris turbines has a rated capacity of 37,500 horse-power, with a full-gate capacity of approximately 40,000 horse-power, and is coupled to a generator rated at 32,500 kilo-volt-amperes, 12,000 volts, 1,565 amperes, three-phase, 25-cycles at 150 revolutions per minute.

SCALING LOOSE MATERIAL FROM THE CLIFF FACE IN THE NIAGARA GORGE.

This photograph conveys a graphic impression of the depth of the fissure through which the river flows after taking its huge plunge. The removal of loose fragments of rock by the scaler, slung in the "bos'un's" chair, is essential to the preservation of the power-house, set by the water's edge.

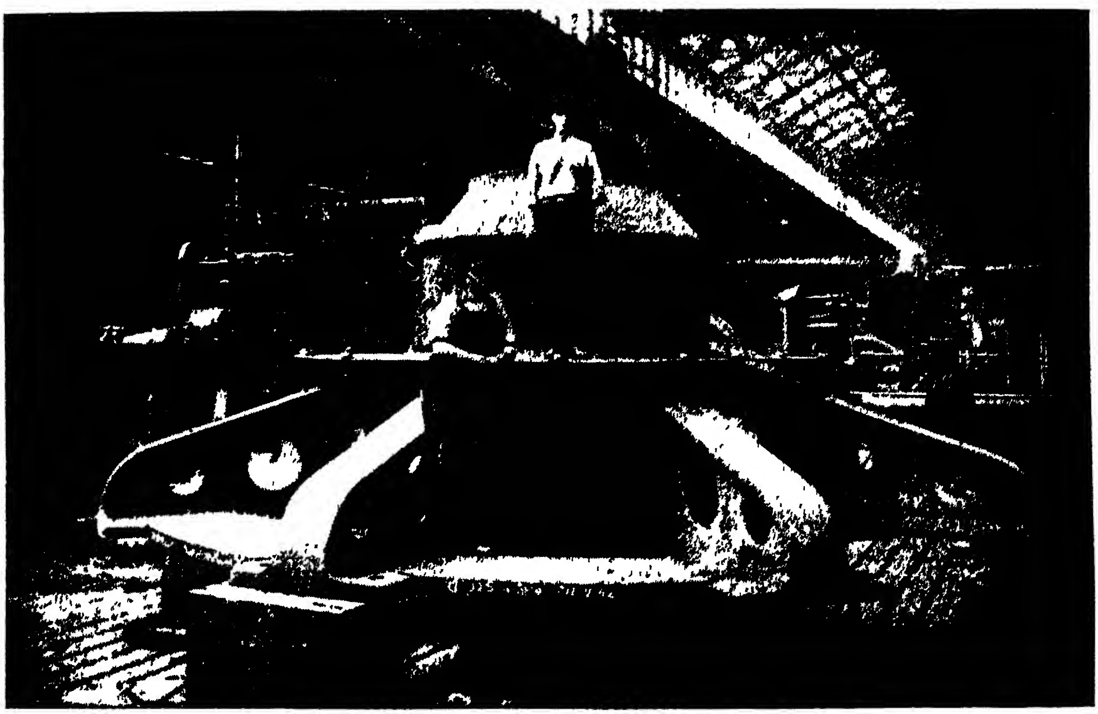
The three generators, practically identical, are mighty machines, as some of the dimensions relating to the one built at the Westinghouse works readily indicate. The total weight of the generator is 650,000 lb., of which the rotor with its shaft represents 318,000 lb.; no less than 33,000 lb. of copper were employed in its fabrication. The rotor has an external diameter of 196 inches, while the outside diameter of the core of the stator is 228 inches. The poles are 65 inches in length, and each scales nearly 2 tons. The rotating element is guaranteed to operate safely at 100 per cent. over-speed. The surface velocity at this excess registers 15,400 feet per minute—175 miles an hour.

The entire generator and the turbine rotor weights, and the unbalanced water thrust of the turbine, are supported by a Kingsbury thrust-bearing located above the generator frame; the total load of the generator alone on this thrust-bearing is 478,000 lb. The inside diameter of the bearing is nearly 7 feet, and when filled to the running level it holds 270 gallons of oil. The ventilation of the generator rotor has also received minute attention. Air for this purpose enters the generator from both top and

bottom, to be forced by fans into the air-gap and spaces between the field-coils. Another motor-driven fan exhausts the heated air from the generator and expels it outside the building. In this way the incoming and outgoing air streams are kept distinct. Dampers are incorporated to permit a certain volume of the outgoing heated air to circulate through the power-house during the winter, to regulate the temperature, and for the comfort of the operators.

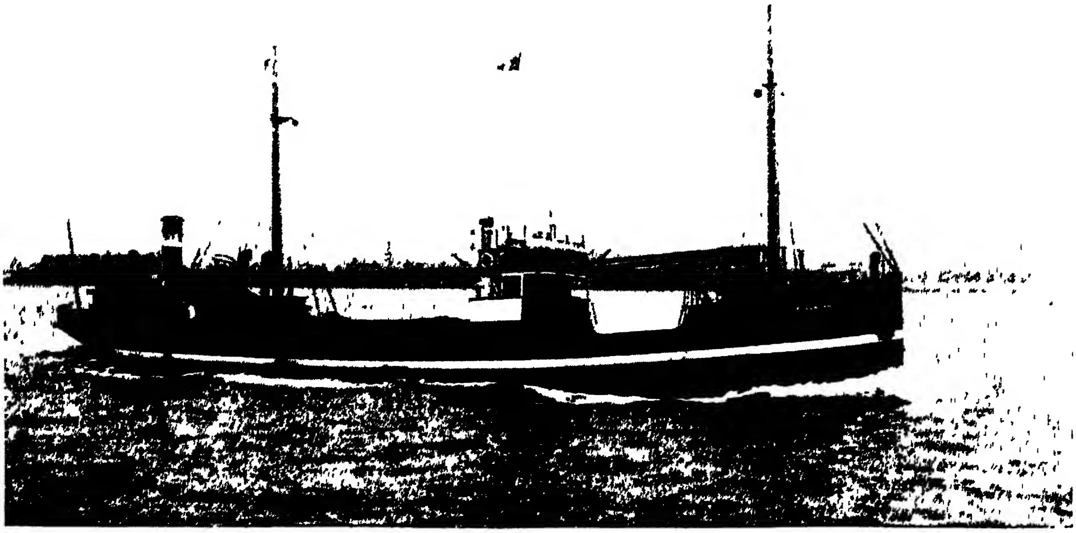
On the Canadian side, through the energy and enterprise of the Hydro-Electric Power Commission of Ontario, social, industrial, commercial and agricultural life has been completely transformed. The metamorphosis on the American bank is equally sensational. The tram-cars serving the city of Syracuse, 165 miles away, are driven by the hydro-electric energy generated at the Falls. The industries, commercial offices and homes of Rochester, and a score or more of other towns en route—and throughout a zone of about 200 miles' radius—are all served with energy from Niagara.

In Buffalo alone there are stated to be 3,000 electrically-driven plants giving employment to 78,000 persons; 80 per cent. of the manufactured products are claimed to be turned out by electric power. The city's annual commerce exceeds £65,000,000. The total annual output of the American Niagara Falls Power Company reaches approximately 2,330,000,000 kilowatt-hours with a peak load of 303,640 kilowatts.



PART OF THE 32,500-K V.A. GENERATOR IN THE WESTINGHOUSE SHOPS.

This huge machine, of which three were built for the American hydro-electric installation at Niagara, weighs 650,000 lb. complete; the rotor with its shaft represents 318,000 lb. It is coupled to a 40,000-horse-power turbine.

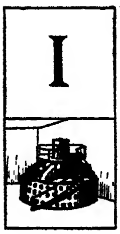


THE FIRST RIVETLESS SHIP

The s.s. *Fullagar*, built by Messrs. Cammell, Laird & Company, Ltd., is welded throughout by the Quasi-Arc electrical process.

Building Ships Without Rivets

HOW THE ELECTRIC CURRENT HAS SUPERSEDED THE BLACKSMITH'S FORGE, THE ANVIL, AND THE HAMMER IN THE SHIPYARD



IN 1886 considerable interest was aroused by the patents issued to Elihu Thomson for his process of welding pieces of metal together by the aid of electricity. His method was simplicity itself. The electric current was supplied to the ends of the sections of metal to be welded, and when raised to the requisite degree of heat the weld was formed by applying enormous pressure. Consequently, as the heat had rendered the metal soft and plastic, the two pieces were squeezed into a homogeneous whole, which, when cooled, was found to be invested with immense strength at the weld. This represented electric welding in its simplest form. The electric current took the place of the blacksmith's forge, while the press superseded the anvil, and the pressure the blows delivered by the hammer.

The names of many prominent savants are associated with the perfection of electric arc welding. Among these may be mentioned the British experimenter, Mr. Arthur Percy Strohmenger, whose name is more intimately associated with many improvements in connexion with accumulators. He evolved the process to which the generic descriptive term "Quasi-Arc" has been applied. As the name implies, a true arc which had always been maintained to be imperative, is not employed. The highly localized heating agency, so characteristic a feature of the electric arc, is turned to full advantage, because this factor is governed

automatically by the nature of the special electrode employed for the purpose. As may be supposed, the electrode itself constitutes the crux of the problem, but this is vitally dependent upon the method of application, which, in turn, is influenced by the character of the material employed for the covering of the electrode.

In the conventional process, wherein a true arc is struck and maintained, the arc is produced between the metal and the electrode, which in some cases is covered with a volatile slag, and in others is bare. A current of high density is used, the arc being drawn to obtain the degree of heat required. In this manner the small portion of the surface of the article under repair, or the pieces of metal to be welded, is raised to the welding heat. At the same time the electrode itself becomes heated to melting-point, and a bead of molten metal falls therefrom upon the surfaces under treatment and, sometimes, is subsequently hammered or pressed to close up the interstices.

Quasi-Arc Process

In the Quasi-Arc process the work is touched with the end of the electrode covered with the indestructible permanent slag, the electrode being held vertically. Contact is established and the current flowing from the electrode to the work produces the arc. The electrode is then inclined to an angle but without breaking contact. This instantly quenches the arc, because the special covering becomes resolved into the igneous condition, and consequently acts as a secondary conductor, maintaining electrical connexion between the work and the metallic core of the electrode. The slag covering, reduced to the molten condition, produces an acid slag, which not only cleanses the metal of the weld from all oxide, but acting as a secondary conductor, enables the operator to maintain a continuous flow of molten metal into the weld, which requires no subsequent hammering to ensure a perfectly homogeneous union. Once the action is started it continues, the electroae melting at a uniform rate so long as it is kept in contact with the work. Furthermore, as the indestructible slag coating acts as a non-conductor it allows the operator to use the electrode close to the work, thereby allowing a lower current density to bring about the desired fusion of the metal. It is interesting to observe that, up to the present, only one material has been found suitable for use as the covering to the electrode which fulfils the foregoing requirements, namely, blue asbestos.

Outstanding Feature of the Process

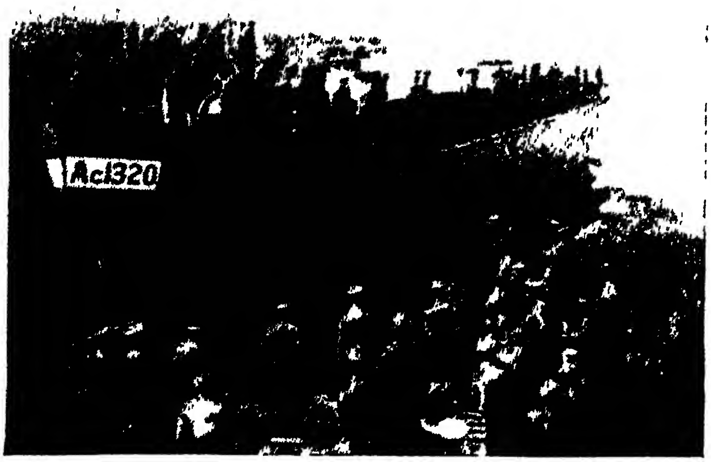
In electric welding by the Quasi-Arc process, the reduction of the slag to the molten state contemporaneously with the metal, is a distinct advantage. When iron and steel are in a fluid condition they have a decided affinity for the oxygen in the atmosphere. It is imperative that such action should be frustrated, inasmuch as the oxygen thus absorbed subsequently exercises a chemical reaction with the carbon contained in the steel, forming an oxide which precipitates porosity of the metal and leads to its ultimate collapse.

Possibly the most remarkable development of the Quasi-Arc is its application to such an established craft as the building of ships. In this industry changes are few and far between. Ship construction is governed by a very exacting organization known as Lloyd's Register of Shipping, whose rules and regulations, representing the sum of widely accumulated experience and knowledge, are as the laws of the Medes and Persians. No sensational development can be translated into practice without the sanction of the authority in question, for the simple reason that it possesses the power of refusing to classify the ship embodying the new idea, and no owner will incur the risk of such denial, inasmuch as it negatives insurance and may even prevent the ship from setting out on a voyage.

Such a powerful organization might

possibly be regarded as imposing a brake upon progress, but experience has taught otherwise. It maintains a technical committee, whose duty it is to investigate all matters of technical import. This body, when a new idea is forthcoming, submits it to searching test and experiment to determine, so far as is humanly practicable, its general trustworthiness in the peculiar field concerned. This committee is invested with great responsibilities, because upon its decisions matters of great moment are dependent. Consequently, it carries out its work with every deliberation and care, the policy of make-haste-slowly being punctiliously observed. From this it will be realized that any favourable decision upon the part of the committee is of far greater moment than may superficially appear; its approval sets the seal of complete success upon a new development no matter how startling and revolutionary it may be.

In due course, owing to the rapid and enormous strides which were recorded, the practicability of employing electric welding instead of rivets for the fabrication of ships became the subject of keen discussion in marine engineering circles.



THE FIRST ELECTRICALLY-WELDED SEA-GOING CRAFT.
A steel lighter built for cross-Channel traffic by the Royal Engineers. It measures 126 feet in length, 16 feet 4 inches beam, and 7 feet 6 inches deep, and has a dead weight of 240 tons.

Riveting, while universally accepted as the most effective method of securing the tens of thousands of different parts together, is not wholly satisfactory. Defective rivets in ships are probably more frequent than may possibly be imagined; this is not surprising when one recalls the number of such small pieces of steel which have to be worked into a hull. Even a 5,000-tonner will absorb a round 500,000 rivets, while to complete the hull of the *Mauretania* upwards of 4,000,000 rivets, representing 700 tons, were required.

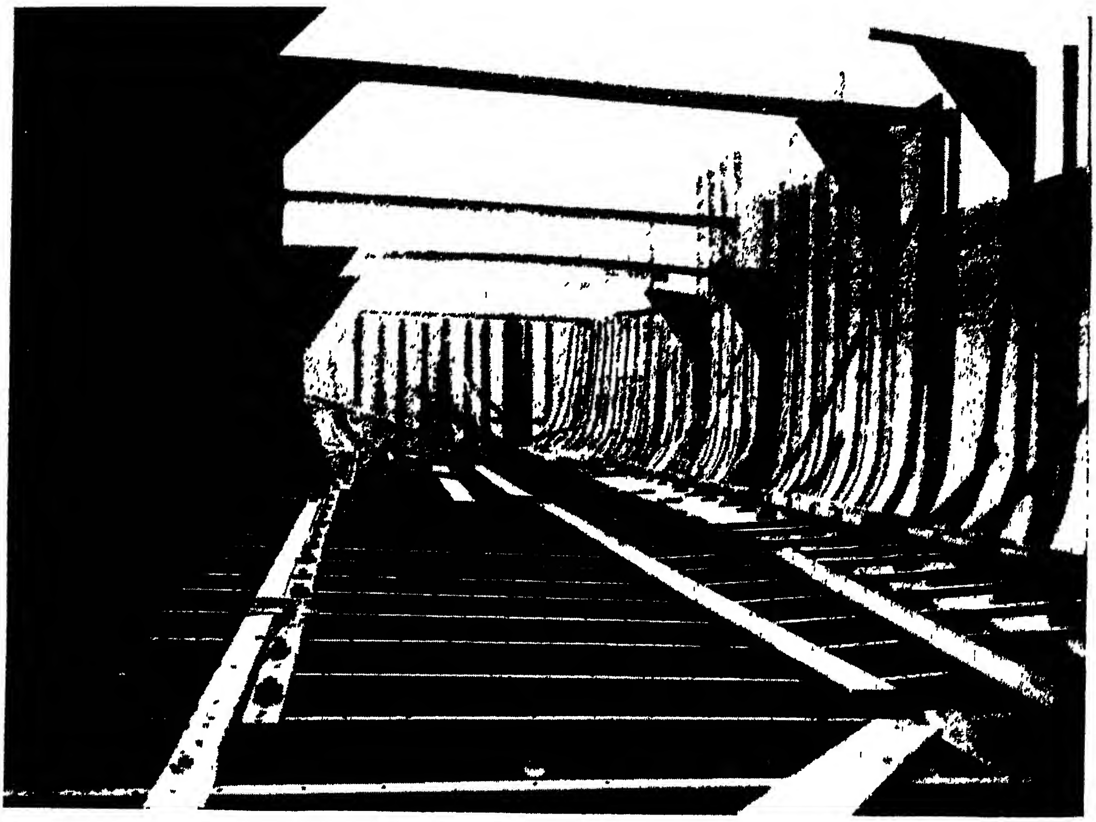
The suggestion that arc welding should supersede riveting was raised, and its claim strongly supported, by relating the increasingly popular method of dealing with rivet defects when they asserted themselves. Instead of driving in a new rivet it was ascertained that a far sounder job could be made by welding the point at which the trouble occurred by means of the electric arc. Consequently, if the electric arc were efficient for making good such defects, why should it not be employed in the first instance, and the whole of the fabric be welded instead of riveted together? In order to obtain convincing testimony concerning the strength of such welding, elaborate experiments were made, and these conclusively proved that an electrically-welded joint, even when applied to the peculiar conditions incidental to ship construction, was far stronger than a similar riveted joint, the margin of increased strength running up to 25 per cent. and more in favour of the first-named.

The contention in favour of direct construction in this manner by the Quasi-Arc process received additional support from the fact that there were more than 3,000

shipbuilding yards and general engineering establishments in the British Isles extensively resorting to electric welding by this means for the completion of repairs of every description. Some of these tasks were of an exceptionally striking character, and would have been virtually impossible of treatment by any other known method. In many instances electric welding proved to be the alternative to the manufacture of a new part.

The result of these discussions was the elaborate investigation of the problem by the Admiralty and the technical committee of Lloyd's Register of Shipping. Several months were devoted to the examination of the process and its application to this field from every angle. The outcome was the elaboration of a series of conditions under which electric arc welding might be adopted instead of rivets, the framing of which at once enables vessels so built, and, in accordance with the specification set down, to be available for classification in Lloyd's Register.

While the foregoing committee was deliberating upon the subject in 1917, the British Admiralty was engaged in a series of practical experiments to determine the possibilities of the process in connexion with the vessels under its control. The data thus obtained proved to be of such pronounced value that the War Office decided to undertake the construction of the first craft ever attempted by this method, and according to the principles of the patents of the Quasi-Arc Company of London; the actual building was carried out by the Royal Engineers under the supervision of Major Hambling, R.E., and his staff.



THE S.S. *FULLAGAR* UNDER CONSTRUCTION.
The electric arc welding invasion of the shipbuilding yard as a principle for the fabrication of ships represents a new departure which may have far-reaching results.

This initial effort, while perhaps unpretentious, nevertheless was historic. The vessel in question was a steel sea-going lighter with a flush deck. It was 126 feet in length by 16 feet 4 inches beam and 7 feet 6 inches deep, having a displacement of 310 tons on a draft of 5 feet 9 inches, the dead weight being 240 tons. Similar vessels were constructed in the Richborough yards in accordance with accepted riveting principles, but the electric system proved to be cheaper. The total cost of completing the work by arc welding was £300, which sum included the electrodes, current, and labour, the cost of the first-named being approximately £180, while current and labour shared the balance in equal proportions. On the other hand the cost of building a sister craft in the orthodox manner, including charges for drilling, riveting and caulking, was £390, while in a private yard the figure reached £450. Thus electric arc welding showed an advantage over riveting in regard to cost by £90 in the one, and £150 in the other instance.

Confidence in the Electrically-welded Ship's Seaworthiness

All apprehensions concerning the strength of an electrically-welded craft were dispelled by the behaviour of this lighter at sea. She was placed in the cross - Channel carrying service, and although the duty to which she was subjected was heavy, and she often encountered extremely rough weather, no signs of starting seams were observed. Incidentally the advantage of electric welding over riveting was brought home very convincingly in another respect. During one passage the lighter went ashore, piling-up on some ragged rocks. The impact dented some of the plates very badly, but the seams held; not one was started. This experience was in striking contrast to that related in connexion with the riveted rivals. In many instances it was found necessary to load the craft at low tide, and while they were aground. This set up severe strains, resulting in the development of leaks at the upper turn of the bilge. Caulking had to be practised to ensure water-tightness, but the defect so frequently asserted itself that, at last, it was decided to make good the seams by Quasi-Arc welding, when no further trouble was experien,ed.

Applications of the Arc

The method of construction was interesting. The plates were temporarily held in position by bolts. The arc was applied and the two ends of the plates fused together. Continuous welding was practised in regard to the external part of the vessel, including the cross-seams, but in the interior, where water-tightness is not imperative, what is known as "tack" welding was favoured. This practice involves the welding of a short section, say, for instance, 3 inches, and then skipping a section of about 6 inches when another 3-inch weld is formed. Of course, when water-tightness is a *sine qua non*, continous welding must be observed. In the case of deck plates "butt" welding was adopted; the plates set end to end, and, so welded, gave a flush surface.

Through the enterprise of the War Office a practical example of what could be done in this field was thus obtained, and it was duly investigated by the technical committee of Lloyd's. This served to confirm the conclusions which it had already formed, the result being that the favourable decision of the committee was promptly made known. The world's leading classification society having appended its imprimatur to the new idea, shipowners and shipbuilders, many of whom had already formed a favourable opinion concerning the process, were disposed to embrace the opportunity for experiment upon an ambitious scale. The well-known shipowners, Messrs. T. and J. Brocklebank and Company, of Liverpool, were the first to take advantage of the new development, and the first rivetless ship properly so-called was taken in hand by Messrs. Cammell, Laird and Company, the eminent shipbuilders of Birkenhead.

This initial one-piece ship, the *Fullagar*, has been built for coastal service. It measures 150 feet in length, 23 feet 9 inches breadth, and 11 feet 6 inches moulded depth, and has a gross tonnage of 425. Quasi-Arc electrodes were exclusively employed in construction, and all butts, seams, and other connexions were completed by the aid of the electric arc according to the patents of the company concerned.

Apprehensions lingered in certain quarters as to whether the *Fullagar* would not develop leaks during the delicate process of launching, when, as is well known, severe strains of an unusual character are imposed upon the fabric. To meet this contingency, the usual precautions were observed previous to the actual launch. But, as results proved, these arrangements were superfluous; the *Fullagar* floated bone-dry, a circumstance which speaks volumes for the workmanship of the welders, as well as the soundness of the principles of the British invention involved.

While the building of ships represents the most striking and sensational development of electric arc welding, some equally noteworthy conquests, especially in the field of ship-repairing, have been accomplished therewith. In fact, it is now regarded as an indispensable part of the equipment of a ship-repairing yard, and the speed and relatively low cost with which damaged vessels are restored to service, even in cases where the character of the injury portends prolonged sojourn in dock to allow new parts to be made, has occasioned considerable attention.

Although the application of electric welding has made enormous strides during the past ten years, it is really only in its infancy. The fields in which it may be advantageously employed are illimitable. Its introduction into the shipbuilding-yard represents its greatest achievement up to date, and one in which there are immense possibilities, as may be gathered from what has been related.

THE PIONEER ELECTRICALLY-WELDED SHIP ON THE STOCKS.
The s.s. *Fullagar* ready for launching. The smooth surface of the hull, due to the absence of rivets, will be observed.

THE "IRONCLAD" MULTIPLE-UNIT EIGHT-CAR TRAIN.

It measures 403¾ feet in length; seats 356 passengers, with standing accommodation for 534 persons—total 890 passengers; weighs 257 tons laden; and is fitted with motors having a collective output of 2,280 horse-power.

Carrying 571,000,000 Passengers a Year

LONDON'S DAILY RAILWAY TRANSPORT PROBLEM, AND HOW IT IS MET BY UNDERGROUND ELECTRIC-TRACTION

NO city in the world presents such a tangled problem in connexion with transportation as London; and no other city provides such a traffic paradox. The more the interurban carrying facilities are extended, the more perplexing becomes the issue—a transportation variant of the established commercial law of accessibility begetting demand. The traffic intricacies of the British metropolis are affected by many factors—topographical, meteorological, commercial, and social. Each exercises a distinct influence, sometimes conflicting and, generally speaking, somewhat irreconcilable.

The whole of the interurban traffic of London has to be carried by train, tram and motor-bus, and of the three it is the first-named which really constitutes the crux of the problem. A few years ago it appeared as if the public were disposed to abandon the railway, but this state of affairs was solely attributable to one cause—persistent adherence to steam-working which had long outlived its period of usefulness in this field.

It was an American, Yerkes, who saved the railway situation. He tore out the steam-power to replace it by the young giant electricity. It was a daring step, but critical situations demand desperate remedies. In his native land Yerkes had snatched several transportation undertakings from bankruptcy and decay by converting them to electrical operation. Many critics maintained that the conservative Londoner would never be wedded to electric

traction underground, but the quidnuncs found the records against them. Before Yerkes consummated his scheme a new and eminently distinctive era in interurban transport of British conception had dawned. This was the deep-level tube, a tunnel circular in section, driven by means of the Greathead shield, lined with steel and working upon the shuttle principle—one tube for each track with cross-overs at each end and at strategical intermediate points.

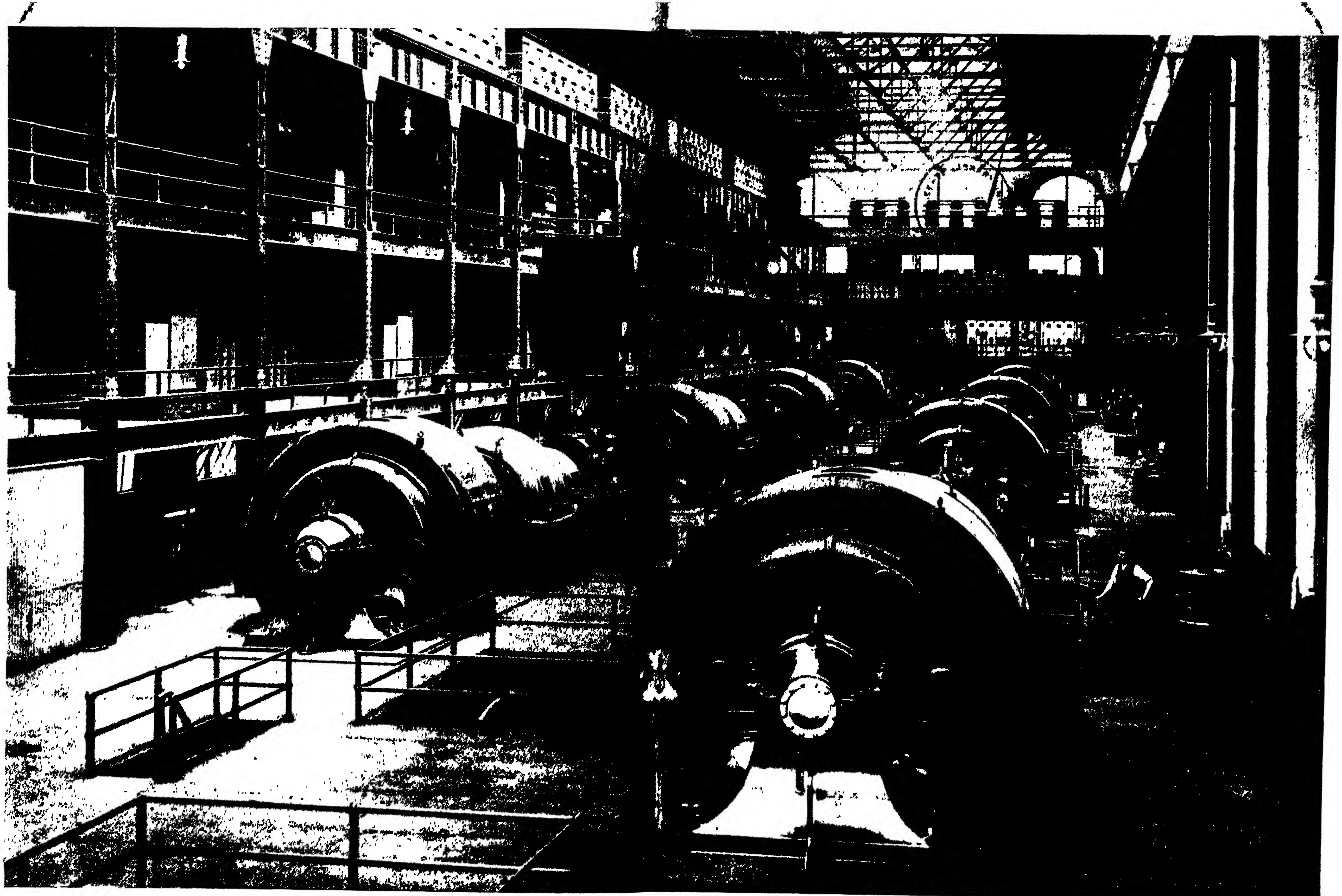
The pioneer tube was a north-and-south one, linking the City with the suburbs of Kennington, Stockwell and Clapham—it South London inaugurated the tube principle, it was the second work of this character, running from the City to the western fringe of the metropolis—the "Tuppenny Tube" or Central London—which set the seal upon this method of underground railway construction. This tunnel was given a greater diameter—11 feet 8¼ inches—which was duly appreciated by the public because it allows the use of commodious vehicles of standard gauge. Electric locomotives, also, were originally installed, but they were subsequently superseded by the multiple-unit coach system.

THE PRECIPITATION OF LONDON'S PERPLEXING TRANSPORT PROBLEM

The trial trip over the Metropolitan Railway in 1863. The privileged passengers, who included many of the notabilities of the day, were accommodated in open trucks hauled by a steam locomotive belonging to the contractor. Contrast with the trains in service to-day emphasizes the advance and advantages of electric traction.

was subsequently extended northwards to Islington and Euston. For the working of this line, the City and South London, electric locomotives were adopted. This practice has been upheld although, with the enlarging of the tunnels to carry modern rolling stock, and the establishment of physical interconnexion with the tentacles of the general tube system which has been woven, the locomotive is giving way to motor-coach practice. While the City and

The successive tube railways represented distinct commercial ventures, assumed for the purpose of improving intercommunication through specific areas. They were short, and, for the most part, no attempt was made to provide the convenience of interchanging. When it came to the conversion of the Underground system a problem of quite another character was presented. The mileage to be transformed was somewhat imposing, but the issue was



GENERATING 78,000-84,000 KILOWATTS TO CARRY 1,250,000 PASSENGERS A DAY.

The interior of the power-house of the Metropolitan-District Railway at Chelsea. The installation comprises eight 6,000-kilowatt and two 15,000-18,000-kilowatt turbo-generators. In the course of the year 260,000 tons of coal are turned into 255,000,000 kilowatt-hours to move 389,000,000 passengers over 63 75 miles of Tube and Underground railways.

complicated from the circumstance that two separate companies are responsible for this vital traffic artery of London. Even to-day these two undertakings preserve their individual corporate existence; each has its own rolling stock and power-house, though the two systems are so completely interwoven in the physical and operating senses as to appear a homogeneous whole to the public.

The Metropolitan, the *doyen* of the world's underground railways, totals nearly 132 miles of track. Of this, 44 miles of double line have been electrified, while the longest continuous stretch of converted line is 55 miles. The Metropolitan-District stretches over 25 miles, but as the tube railways have been consolidated therewith, and represent a further 38·75 miles, the total mileage of this system is 63·75 miles. Amalgamation of the tubes with the District has bestowed innumerable benefits upon the restless population of London. Physical connexions have been made at all points of intersection which, with the complete transfer system adopted, allows changing at these centres. In this manner the completion of an underground metropolitan belt line, linking all the terminal stations of the great trunk railways, has been achieved, thereby solving that searching problem of "getting across and about London."

The Founts of Power

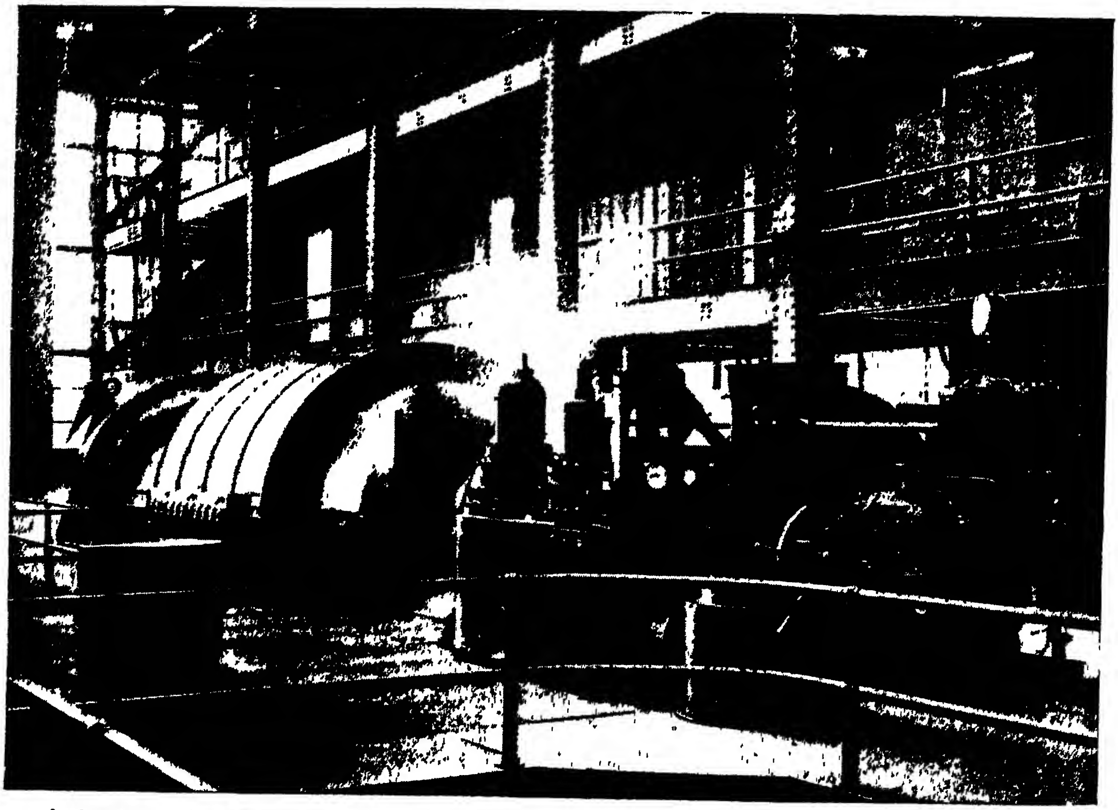
The Underground network draws its electrical energy from three central stations. One, at Chelsea, constitutes the fount of power for the Metropolitan-District, with its tubes, except the Central London, which is dependent upon its own station at Wood Lane. The third power-house, at Neasden, serves the Metropolitan.

The Chelsea power-house covers an area of 3½ acres and has a water frontage of 1,100 feet on the Thames and Chelsea Creek. The main building, housing the electric equipment, of the steel-frame type, measures 453 feet in length by 175 feet in width and 140 feet in height. The whole of the plant is driven by Parsons turbines. The original installation comprised eight turbo-generators, each rated at 5,500 kilowatts, subsequently increased to 6,000 kilowatts, bringing the total output to 48,000 kilowatts. Owing to the increase of the load it became necessary to introduce further units, the first of which was completed in 1915, while the second was brought into service in 1921. Each of these units is of 15,000 kilowatts economic rating, or 18,000 kilowatts full rating under continuous load conditions, but the second unit is a distinct advance upon its predecessor. Whereas the former gives its rated output at 1,000 revolutions per minute, the second has a speed of 2,000 revolutions per minute. By the installation of these two high-powered units the output of the station was raised to 78,000-84,000 kilowatts. Three-phase current at 33⅓ cycles 11,000 volts is delivered, and is transmitted at the generated pressure through 360 miles of specially constructed cable to the various sub-stations, where it is reduced to 600 volts, at which potential it is fed to the conductor rails for the motor-coaches. Two conductor rails are employed, one set outside, the other placed midway between, the running rails.

Power-house Auxiliaries

The power-house is interesting in regard to many of the auxiliary details contributing to the saving of labour, time and money, which, in turn, conduce to higher efficiency. The 15,000-kilowatt turbo-generators impose a heavy demand upon water for condensing the exhaust steam. When the first of these units was installed the call for more water for the condenser, which has a cooling area of 30,000 square feet, and can condense 180,000 lb. of steam per hour, necessitated the driving of a tunnel, 94 inches in diameter, by means of the Greathead shield, from the power-house to the adjacent river. This wide tunnel is divided

horizontally into two conduits; the upper carries in the fresh circulating water, while the discharge from the condensers is returned to the Thames through the lower passage. To ensure the circulation of the voured in enormous volume, and a large reserve must be carried to meet emergency. The main coal storage provision is a steel tank, 95 feet in diameter, and capable of receiving 14,000 tons. It is charged with

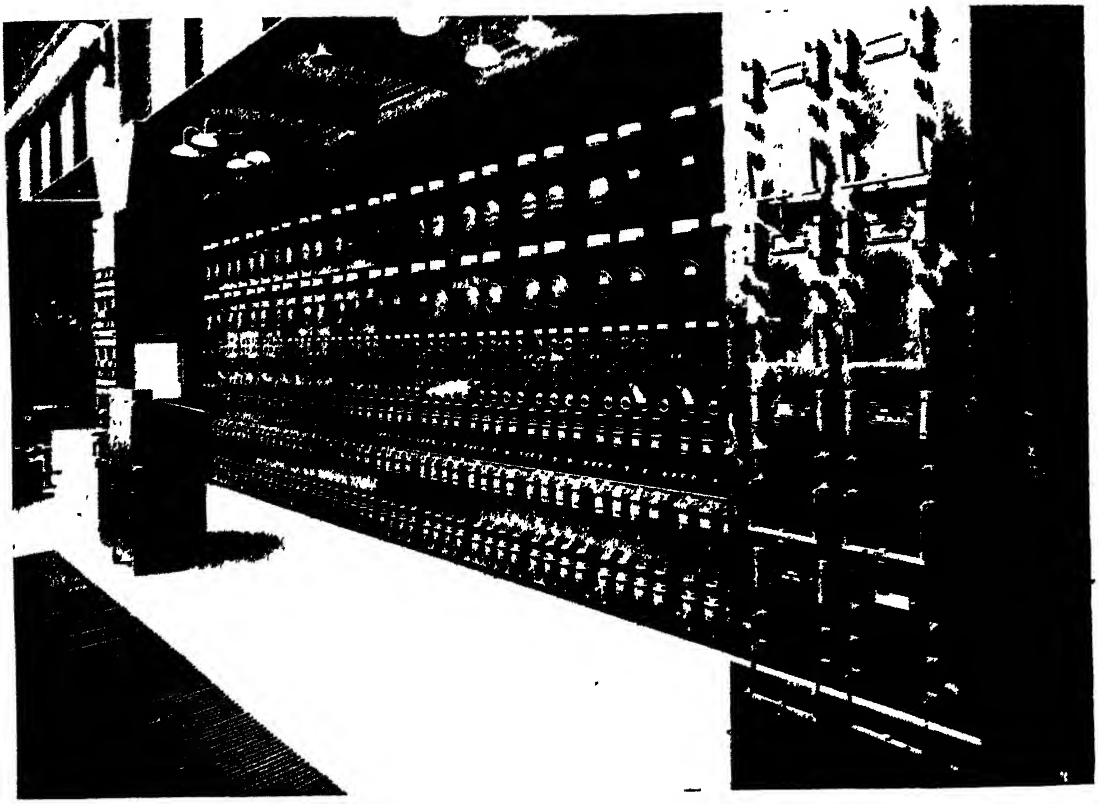


A GIANT 21 000-24,000-HORSE-POWER PARSONS TURBINE COUPLED TO A 15,000-18,000-KILOWATT GENERATOR AT THE CHELSEA POWER-HOUSE.

Increasing traffic, with its demand for further power, necessitated the installation of two of these huge units.

water, pumps, each driven by a 550-horse-power electric motor, are installed in duplicate. At the entrance to the condensing water-supply is a screen pit, to arrest any trash brought down by the river; these screens are of the revolving type with electric motor-drive, and the power units are mounted on the screens themselves. For the periodical cleaning and overhauling of these screens there is an overhead electrically-driven gantry crane. Therewith each screen can be lifted intact out of its pit.

The coaling system is also of more than passing interest. Obviously fuel is devoured ... water, which not only safeguards the coal against spontaneous combustion, but also acts as a preservative. When the tank is fully charged the fuel supply to the boiler-house can be assured from the tank by gravity and an electrically-driven conveyer belt; but, under normal conditions, the coal is delivered direct to the boiler-house from the barges. The side of the storage tank is provided with an opening through which the coal falls on to the belt to be borne to the furnaces. When the coal in the tank falls below a certain level, direct gravity-feed to the conveyer belt is superseded by another method. A set of rails



THE SWITCH-BOARD AT THE CHELSEA POWER-HOUSE.

The distribution of the current to the various points throughout the system, and its many applications for the supply of light, heat and power, demand an elaborate system of control.

spans the tank, and along this track travels an electrically-operated grab. This lifts the coal from the tank and discharges it into a hopper alongside, whence it falls by gravity on to the conveyer.

The coal is brought to the generating station by barges, and is electrically unloaded by gantry cranes. The latest addition to this installation comprises a steel tower set over the end of the conveyer belt and fitted with coal receiving gear. Coal is moved to the tower by an electrically-driven crane at the rate of 40 tons an hour in two-ton mouthfuls, and the equipment of this element of the coal-handling installation includes machinery whereby the fuel is automatically weighed, and also a motor-driven coal-crusher which reduces the coal to the size desired for the mechanically-fed furnaces.

As already mentioned, the Metropolitan maintains its corporate individuality so far as operation and administration is concerned. The system is completely self-contained and independent, the necessary power being generated at Neasden. The equipment of this power-house comprises six turbo-alternator units complete with jet condenser plant and other details. The latest addition to the station, which substantially represents the companion units, is a 12,000-kilowatt—16,100-horse-power—turbo-alternator set constructed by the Metropolitan Vickers Electrical Company, Limited. It comprises a Rateau impulse-type turbine, running at 2,000 revolutions per minute with steam at a pressure of 250 lb. per square inch and superheated to 650° Fahr., coupled direct to the alternator. The latter furnishes three-phase, 33⅓ cycles current at a pressure of 11,000 volts. It can carry an overload of 25 per cent.—15,000 kilowatts or 20,100 horse-power—for two hours.

The complete weight of this unit is 140 tons. The alternator is totally enclosed, the air required for ventilation—45,000 cubic feet per minute—being cooled by means of a cooler installed within the foundations. The turbine is connected to a low-level type multi-jet condenser placed immediately beneath. When the set is running at normal full-load the condenser requires about 11,600 gallons of cooling water per minute. This delivery of water is handled by twin pumps which, together with two Leblanc type rotary air-pumps, are driven either by a 590-horse-power electric motor, or by an auxiliary turbine running at 4,500 revolutions per minute and coupled to suitable speed-reduction gears. Steam is raised by six Thompson straight water-tube boilers with a total heating surface of 39,560 square feet, and having normal and maximum evaporating capacities of 158,000 and 197,500 lb. per hour respectively.

The total output of the six turbo-alternator sets is 60,000 horse-power. To maintain the demand made upon them, coal is consumed at the average rate of 233 tons every twenty-four hours—nearly 10 tons per hour. Fuel is fed to the furnaces from overhead bunkers, which are of sufficient dimensions to receive 4,000 tons. One interesting feature of this station is the cooling-tower installation, which is able to deal with 2,000,000 gallons of water per hour.

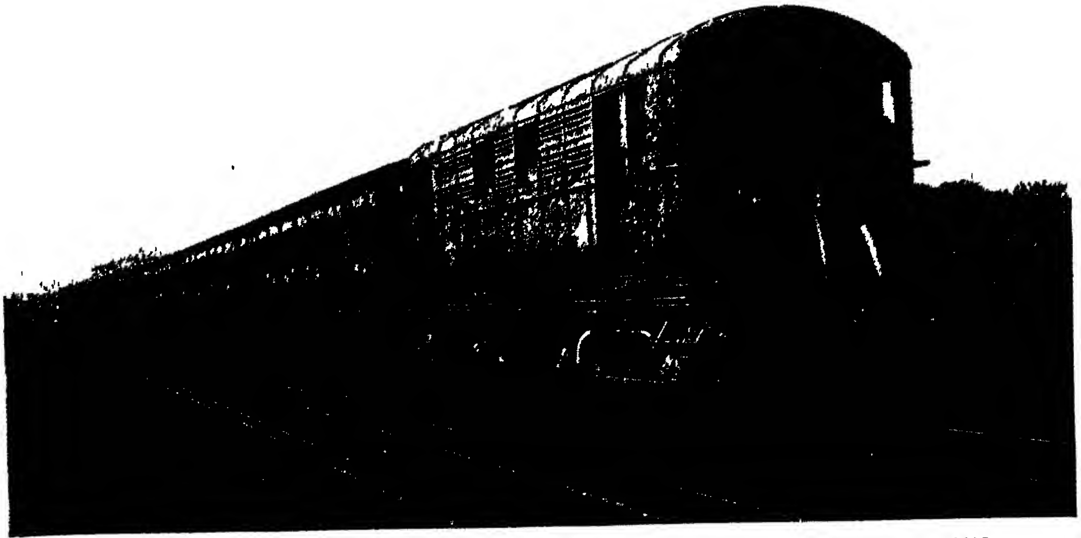
Coal is a big item in the bill for the maintenance of the fast and frequent service which the Underground provides for the travelling public of London. No fewer than 345,000 tons a year are consumed for the production of the necessary current. Of this total the power-house at Chelsea

PRODUCING 60,000 HORSE-POWER FOR THE ELECTRIC OPERATION OF THE METROPOLITAN RAILWAY.

The power-house at Neasden has six turbo-alternator sets. The latest addition, substantially representative of the companion units, delivers 12,000 kilowatts under normal rating, and 15,000 kilowatts —or 20,100 horse-power—for two hours.

consumes 260,000 tons, while that at Neasden imposes a toll of 85,000 tons upon the country's coal supplies during the twelve months.

So far as the public is concerned, the enormous volume of electrical energy produced at Chelsea, Wood Lane, and Neasden is considered from only one angle—individual convenience. During the course of the year the enormous army of 571,000,000 passengers is carried over the complete network—389,000,000 by the Metropolitan-District and Tubes and 182,000,000 by the Metropolitan-District railways respectively. When there are 1,850,000 individuals to move during the twenty-four hours, the complete satisfaction of one and all presents a supreme problem.



MAKING SPEED WITH A 1,400-HORSE-POWER ELECTRIC UPON THE METROPOLITAN.

For the outer suburban services, reaching to the rural corners of the Home Counties, this form of electric traction is eminently successful. By placing the motor unit at the head of the train, rolling stock designed for haulage by steam-power can be used.

The paramount objective of those responsible for the operation of the network is the provision of the maximum carrying capacity per train combined with the maximum number of trains per hour. Both factors have sharply defined limitations which are speedily attained. The former is governed by the length of the platforms, while the second is subservient to the promptitude with which the trains can be dispatched, and the nimbleness of the public. From this it will be seen that these two vital considerations are intimately correlated.

Experience has conclusively proved that the most effective means of attaining the desired end is by the use of the multiple-unit coach system. Therewith a train can be composed to any length up to the limit imposed by the platform accommodation, and in accordance with the density of the traffic, to the highest efficiency, for the simple reason that the propelling effort is distributed throughout the train, instead of being concentrated at one end as under locomotive conditions. The multiple-unit practice may be said to represent the electrical traction engineer's expression of the precept, " many a mickle makes a muckle," because, as the train length is increased or decreased, so is the proportion of driving effort augmented or reduced.

With the latest rolling stock, built

throughout of steel, the standard train comprises eight coaches, giving a total length of 403 feet 9 inches, and representing a dead laden weight of about 257 tons. Throughout this train are distributed three motor-coaches, each fitted with four motors of 190 horse-power, so that the aggregate tractive effort available is 2,280 horse-power for the complete train. This broadly corresponds to the attachment of a locomotive of equivalent power at the head of the string of vehicles as in steam-practice. Each train is able to carry 356 passengers, all seated, but has standing accommodation for 150 per cent. increase, or 890 passengers under peak-load conditions, that is, during the rush hours when traffic attains its highest pressure.

1,400-horse-power Electric Locos.

When one ventures beyond the avowedly City area, the conditions are somewhat different, and favourable to the employment of electric locomotives, since these units can be employed to haul the rolling stock formerly used under steam traction. This is the reason why the Metropolitan Railway has turned to electric locomotives of 1,400 horse-power — the most powerful in the country at the moment — in connexion with the services reaching out to the rural residential corners of Hertfordshire, Middlesex and Buckinghamshire.

The difficulty with which the average steam-locomotive is able to get under way with the maximum load is familiar to all, and it is this delayed acceleration which reacts against the steam-power utility of interurban transportation. Quick acceleration is the outstanding feature of electric service. The 257-ton train is able to accelerate to a speed of 30 miles an hour in thirty seconds from a standstill. When the Central London Railway was planned it was decided to assist this salient characteristic of electric duty. In profile the alignment of the railway resembles a huge switchback, with the stations set on the humps. The train at the moment of starting is at the top of the "hill," and immediately comes under the influence of gravity and the propelling effort exerted by its motors. The descent continues for some distance enabling the train to attain its highest speed very quickly. The approach to the succeeding station is inclined; consequently a retarding effect is obtained. Although the impetus gained by swinging down the bank is expended in forcing the weight up the following grade, sufficient power is expended by the motors to maintain the way on the train until it is desired to stop. By shutting off the power, the run against the collar to breast the brow slows down the train, so that only a slight application of the brake is required to bring the moving mass gently to rest.

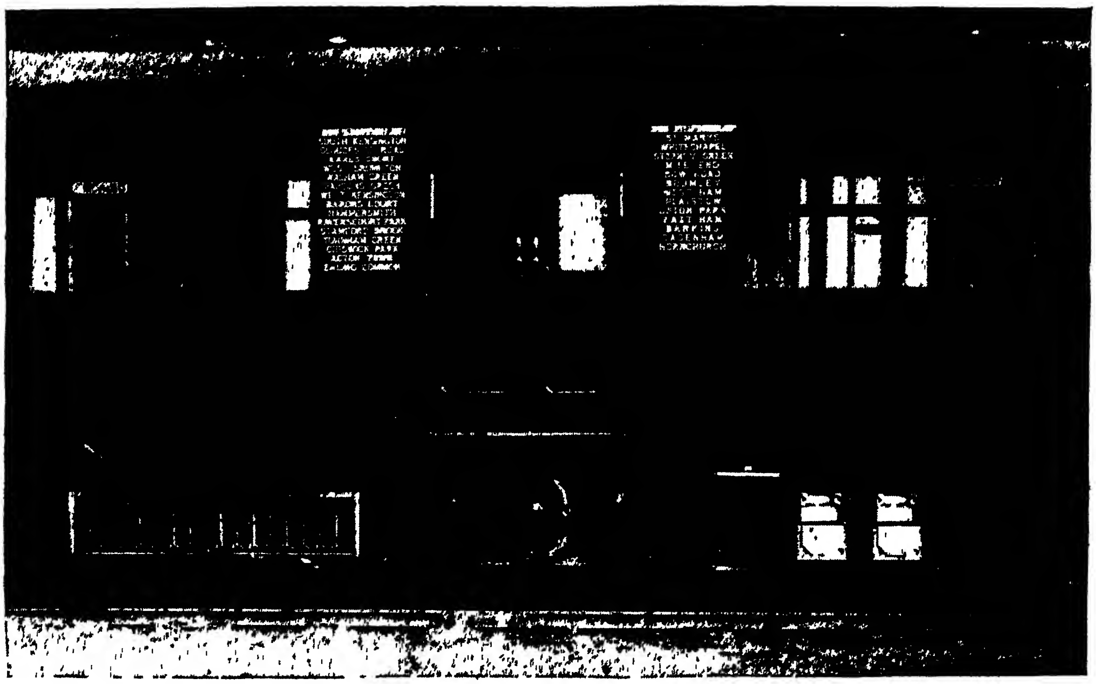
Starting and Stopping

On the Underground, which was built in accordance with established standard surface railway practice, there is no such scientific assistance afforded to the train, either in starting or stopping. The motors have to go "all out" to overcome the inertia of the heavy load, and, in the starting effort, another great advantage of electricity is asserted, namely, the ability to push the motor a further 20 per cent. or so above its normal rating for a few seconds, or until the wheels commence to slip; this contributes, to a very marked degree, to the rapid acceleration.

Stopping is just as important an operation upon such a system as the Underground, where the stations are placed somewhat closely together—the average is less than ¾ of a mile—because it is essential to bring the train quickly yet quietly and smoothly to rest in the interest of the passengers' comfort. The problem of promptly stopping a train weighing 257 tons, which is travelling at 35 miles an hour, to meet interurban conditions, has occupied several years of close study, but it is achieved now with the quick-acting electrical Westinghouse brake. Starting and stopping

—rates of acceleration and deceleration—are now on level terms. Indeed, in emergency, the train, while travelling at 35 miles an hour, can be pulled up in its own length.

Rapid acceleration and deceleration, coupled with "liveliness" upon the part



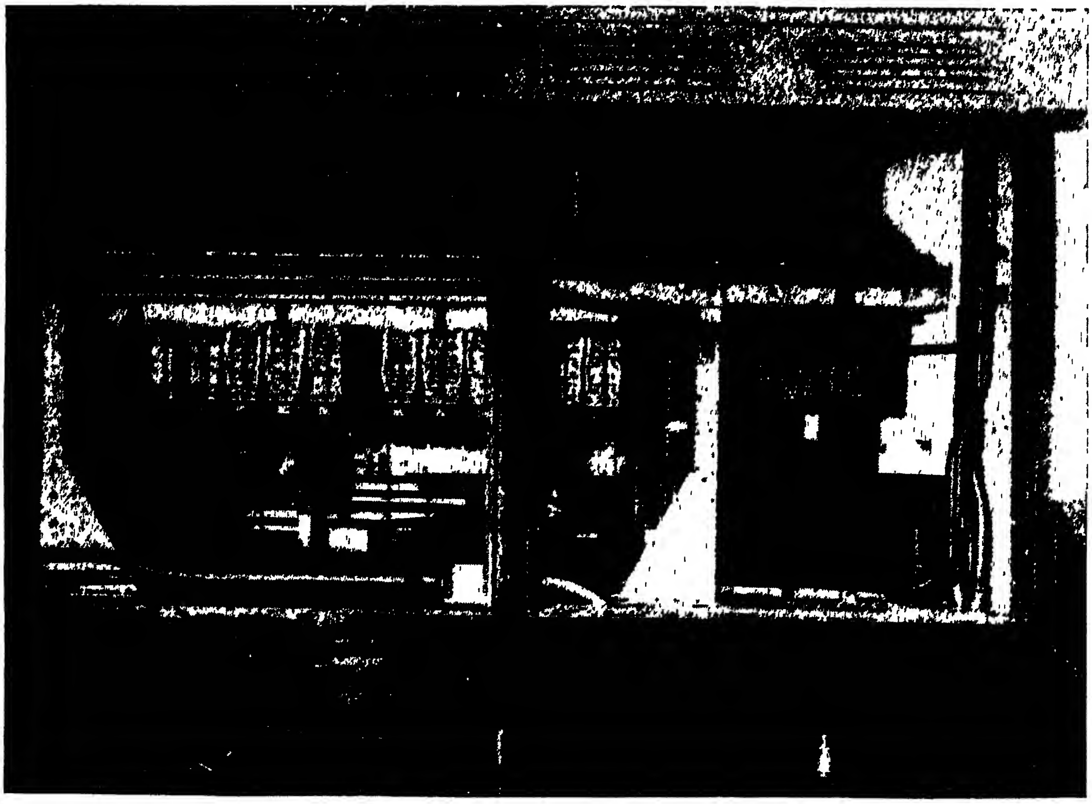
MOTOR COACH. SHOWING CONTACTORS AND OTHER ELECTRICAL DETAILS

Upon the Underground system the electrical equipment is mounted under the main frame of the vehicle, because ample head-room for the coach is available.

of the passengers in boarding and alighting, especially the last-named, determine the frequency of service. The interval for station detention varies according to the density of the traffic. During the rush hours an interval of 28 seconds is allowed at the busiest stations; when this period is exceeded, delays to the trains following ensue. Undue delay at one station affects every succeeding train over a considerable distance, though in diminishing degree. For example, if a train be detained at Sloane Square the repercussion is felt at Mark Lane, 4 miles behind, and between these two points 11 trains are kept behind their scheduled timing. It will thus be seen that smooth and punctual working of the system is largely governed by the passengers themselves.

The volume of traffic handled by the Underground during the daily rush periods is almost incredible. Between the Mansion House and Sloane Square no fewer than 42 trains are passed per hour—the trains follow one another at an average interval of 85·7 seconds—a performance unequalled upon any other railway in the world. The circumstance, that some 25,000 passengers are carried and dropped at Victoria to feed the adjacent trunk railways, during the hour, conveys some idea of what the movement of passengers through the British metropolis means, and is remarkable because it is repeated simultaneously at half a dozen or more other stations along the 3·297 miles between the two points above mentioned. The situation at Charing Cross is even more complex. Two tube railways also serve this point, and there is a considerable volume of changing over from one

Motor-man's cab of Tube train, showing the adjoining compartment, with louvres in side and roof for ventilation, housing contactors and other electrical equipment.



Interior of the contactor compartment of Tube train as seen from the track when louvred shutter is raised. Reduced head-room compels provision of a special compartment above instead of beneath the frame.

MULTIPLE-UNIT COACH TRACTION UPON THE TUBE RAILWAYS.

line to another. The handling of the immense transfer business to and from two tube railways, and the maintenance of the average interval of 85 seconds between the trains, afford together striking testimony to organization.

Transfer Centre for the Home Counties

On the northern half of the Inner Circle, the Metropolitan Railway is called upon to cope with broadly similar conditions at Baker Street, whence there is extensive debouching from the Underground, so-called, to the rural parts of the Home Counties. During the course of the day 1,432 trains are handled, including no fewer than 634 cars during the rush hour; while the monthly running record of the Metropolitan rolling stock is 2,000,000 car-miles. In the perusal of the traffic records of this intensely busy junction, we obtain a graphic impression of the far-reaching revolution which electricity has wrought. Immediately previous to the conversion, the steam-hauled trains handled at Baker Street per day numbered 750—a notable achievement—but by the change-over the capacity has been practically doubled.

The task of handling passenger traffic in London is more acute than in any other city, because it is never constant. The weather alone is a most disturbing factor; rain, fog, and snow drive thousands who normally favour surface transit, to the Underground. On the other hand, sunshine sends a very large proportion of London's floating population to the open air; a passing shower returns them to the electric steelway, even for a short journey. Passing events also attract thousands of additional passengers, who, for the most part, elect to return home at the same time as those who move regularly to and from the City every day.

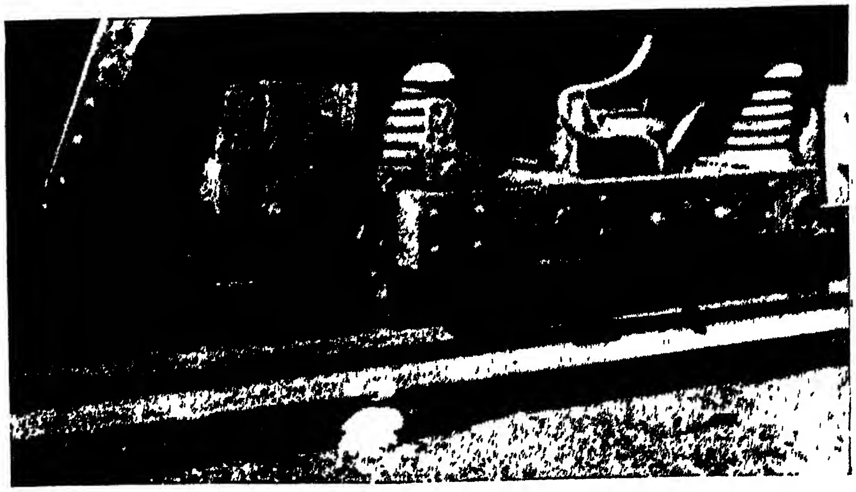
Frequency of service, with safety and high travelling speed, demand a perfect controlling system. So far as signalling is concerned dependence upon the human factor is reduced to the minimum, except at those points where the introduction of the brain is essential, as for instance, at junctions and cross-overs. In such instances the manually-controlled cabin must be introduced. The automatic system is complete, simple in working, and robust in construction, with the additional integral feature of giving the danger position in the event of a defect asserting itself. So reliable and so sturdy in construction is the Underground system that, on the average, it might be found to prove wanting only once in a million movements.

Automatic Train Control

Automatic operation necessarily means that provision must be incorporated to prevent the train disobeying the signal. The human element is more likely to err than mere mechanism. The latter may and sometimes does make a mistake, but its failure is not accompanied by any serious result; the train is merely delayed. On the other hand, should the man behind the control of the train fail, then disaster swift and sudden may ensue. Train control on this system is more elaborate in the mere recital as to "how it is done" than in actual operation. The motor-man has control of his train completely, so long as he is competent; should he fail, the automatic system picks him up, and promptly restores the safety conditions. Sudden illness or death may overwhelm the motor-man while his train is making full speed, and this was the risk to be dreaded. This apparent menace to safety in dependence upon one man is ingeniously eliminated by the design and working of the controller handle. This must be permanently held in position because the pressure exerted by the hand counteracts the opposition of a spring. The instant the pressure of the hand falls, no matter how slightly, the spring comes into play and forces the handle back to the "off" position, cutting-out

the motors, and applying the brakes simultaneously. From the function of the spring this control is known as the "dead man's handle," and it is the most effective single device with which the electric train is fitted.

The driver, however, may fall a victim to momentary distraction without releasing his pressure upon the controller — a condition which the "dead man's handle" cannot possibly frustrate. Yet this danger is effectively anticipated. During a passing lapse a driver may thus unconsciously pass a signal set at "danger." In an instant the control is taken out of his hands, the motors cut out, and the brakes applied. The assumption of mechanical control in this instance is from the track itself. Beside the rails, and connected to the signalling apparatus, is the device known as the automatic train-stop. When the signal is lowered and the line is "all clear," this device drops out of the way; but, should the signal be at danger, it projects vertically. Should the oncoming train rush past the signal, this protruding arm comes into contact with a lever upon the motor-truck of the train, which in turn trips a cock of the Westinghouse quick-acting brake system. The full braking effort is instantly applied, and this is sufficient to pull-up the train, even should all the motors be developing full power.



HOW THE MOTOR COLLECTS ITS CURRENT.
The "plough," showing the shoe whereby the continuous sliding contact is established with the outside feed-rail.

The circumstance that the signalling system itself is able to stop the train might be construed into an adverse feature, as tending to render the motor-man less attentive to his duties, from the knowledge that the automatic train-stop will effectively rectify remissness upon his part, and thus extricate him from a possibly dangerous situation; but the intervention of the automatic train-stop involves a certain amount of delay, because the normal braking condition of the train—the air-pressure—has to be restored, and this fact becomes known to the traffic controller who promptly launches his "Please explain!" To acknowledge delay from the operation of the automatic train-stop, unless there be very material reason, is therefore a severe reflection upon a driver's capacity. The automatic train-stop is introduced for a specific purpose in the interests of safety, not as a reed to support an incompetent or negligent driver.

When the train passes a signal the restoration of the latter to the danger position is automatically carried out by the train itself. Combined electric and pneumatic agency is necessary for the actuation of the apparatus. One of the pair of running rails is converted into a continuous electric conductor by bonding the successive rail lengths with a length of copper. The second rail is similarly connected-up but in

THE "DEAD MAN'S HANDLE"

The greatest single safety-device upon the electric train Should the driver be stricken down while at his post, the release of his grip causes an opposing spring to throw the lever to the "off" position, automatically cutting off the current from the motors, and applying the brakes to bring the train to a standstill.

such a manner as to be subdivided into sections, the length of each of which depends upon the signalling requirements. This subdivision is effected by the introduction of insulating material between the rail-ends at the desired points. Thus the track is converted into a series of complete and successive individual electrical circuits, each of which governs the signals in that circuit.

When a train has run out of one block into the next, the signals at the entrance to the preceding block, through the passage of the current, are held to the "all clear" position; while that at the entrance to the block through which the train is passing is set to "danger," to be held there until the train has passed out at the opposite end, when it becomes energized and gives the "all clear" position. Current is required to set the signal "all clear," but when the danger reading is necessary, as, for instance, for the signal guarding the entrance to an occupied block, the electrical circuit is short-circuited from rail to rail. The mechanism of the signal, thus deprived of current, flies to the "danger" position through gravity. The energy for operating the signalling system is supplied from the generating station. Should the electrical supply, either for the signalling system itself or for the railway as a whole, suddenly fail, every signal throughout the system, which is automatically actuated, would fly to "danger" from lack of power. Similarly, should any defect assert itself, either in the signal or its mechanism, the "danger" position is indicated whether it be correct or otherwise. It will be seen that the primary requirement of an automatic signalling system, namely, "danger" indication in the event of a defect, is completely fulfilled, for the simple reason that such reading is governed, not by electrical but by gravitational force.

The train controls the signal and the signal controls the train. This would appear to be a perfect cycle, but there is one other detail to be considered. The driver must be kept acquainted with the circumstance that the signal is in the condition to control the train and that the train can control the signal. This is done visually and simultaneously, at the station, to

satisfy all those in direct control of the train and its movement. On the Underground the signal-light indications are red for "danger," green "line clear," and orange for "caution." (The latter takes the place of the distant signal in general railway operation, because it repeats the adverse setting of the home signal guarding the approach to the next station.)

There is a fourth light—purple. This is not a regular signal; it is a brake-test device. It glows as the train glides into the station to suffer extinction when the train stops. The light is actuated by the trip-cock carried upon the train for operation by the automatic train-stop in the event of over-running a signal. Its brief glow indicates that the trip-cock has not suffered displacement by vibration, shock, or fouling any obstacle upon the track; but should this light continue to glow after the train has come to a standstill in the station, it warns the driver that his trip-cock is in need of adjustment. The driver cannot possibly miss this visual indication, because it is placed beside his starting signal.

Fog is the enemy which is dreaded as much on the Underground as upon the trunk railways, although it is naturally experienced in its most acute form upon those sections where the railway emerges into the open air. The system of protection originally afforded was that usually favoured—an explosive signal given by a detonator automatically placed on the line; but the audible warning has been superseded by one of a visual character. Placed beside the track, level with the driver's line of sight, are two powerful electric lamps, throwing a green or an orange light. It is an extension of the repeater signal installed throughout the system, but modified to meet the new condition. The light thrown indicates the position of the succeeding signal 100 yards beyond—a sufficient distance in which to pull up the train quietly if necessary. Experience has proved this system to be more efficient than the detonator, because the flash of the light squarely upon the driver's face cannot possibly be mistaken. Economically the new idea is decidedly preferable;

UNDERGROUND SIGNAL CABIN SHOWING ELECTRICALLY-ILLUMINATED TRAIN CHART.

Although automatic signalling is the paramount system of controlling train movements, manually-operated cabins are indispensable at junctions and crossings. They are fitted with electro-pneumatic levers.

the outlay upon detonators is saved, as well as the wages of the fog-man. It is also additionally efficient because it is directly connected to the automatic signalling system, and eliminates that dependence upon the human factor which the fog-man represents.

571,000,000 Passengers a Year

The uneventful transportation of 571,000,000 passengers during the year by train represents only one phase of the traffic problem. The other is the rapid and equally smooth circulation of the passengers to and from the platforms. Obviously, if the approaches to the trains be inadequate, or prone to severe congestion, the efficiency of the actual train-work must be lowered. So far as the shallow section of the network is concerned—the former steam-operated railway—this question is met by the provision of sufficient ramps and staircases which, in every instance, owing to the line being a few feet below or above the level of the street, are comparatively short and accordingly favour quick passage to and fro; but the deep-level tubes present a different problem, especially when, as in one instance, the rails are 100 feet below the street. Upon the introduction of this form of railway to the British metropolis lifts were introduced to overcome the vertical section of the journey, and were somewhat rapidly developed, until elevators, with a travelling speed of about 180 feet per minute, and of sufficient dimensions to accommodate 45 to 116 people, were installed.

The elevator, however, is not adapted to this duty. The length of travel is not sufficient to permit a high speed being attained, as, for instance, the 600 feet per minute incidental to the sky-scrapers of America; while valuable time is lost at each level in discharging and taking-on passengers. It may be safely assumed that of every hour about 45 minutes represents dead time—the aggregate period the lift is standing still at upper and lower levels to take on and discharge passengers. When the necessity for speeding-up transit became imperative, it was recognized that the elevator constituted the weakest link in the chain, and so a solution to this problem was sought. It was found in the escalator, or moving staircase, which, upon its debut, was considered to be an attractive side-show at exhibitions, comparable with the joy-wheel, water-chute and similar novel and sensational divertisements. But the movie-stairs have been converted from an amusement into one of the most useful methods of carrying large numbers of people from one level to another with speed, safety, and comfort.

Devices for Speeding-up

Many other subtle devices, unknown to the public, have been introduced to assist in speeding-up interurban railway transportation. The existence of many is revealed by the improved service which is offered; others are apparent. The control of the traffic in the vicinity of Earl's Court, especially west of the station, was productive of considerable delay under the methods which formerly prevailed—a heritage of steam-locomotion days. This is the largest station on the system, having 4 platforms, and during the periods of pressure 86 trains, or 564 cars, are cleared east and west on the Metropolitan-District Railway during the hour. It is the station where many roads meet, and the negotiations of the gridiron of crossings not only presented an intricate traffic problem, but reacted completely against any attempt to accelerate the service with safety. The difficulty was appreciably alleviated by the provision of two flying junctions, the boring and equipment of the tunnels for which cost a round £100,000.

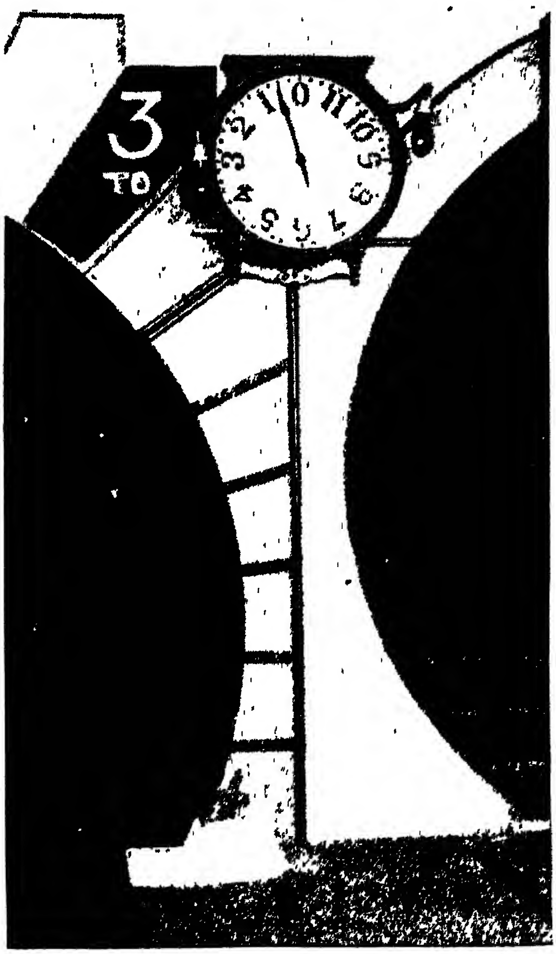
At certain stations an unconventional clock is installed—a dial with the figures inscribed anti-clockwise, and upon which the single hand, also as if out of perversity, travels in the reverse direction.

This clock fulfils various purposes and enters into the machinery for the maintenance of the service. It indicates the number of minutes which have elapsed since the last train left the station, and, furthermore, informs the driver of an approaching train exactly how far he is behind the allotted interval relative to the preceding train—no easy problem during the rush periods with a service of some forty trains an hour. Punctual running is the essence of efficiency of service, and while it is realized that passengers contribute very materially to the delay of a train, it is imperative that such detention should not be accepted by the driver as a cloak for concealing any remissness upon his part.

The traffic controller is in intimate and constant touch with every yard of the system and every train in movement. He maintains a particularly sharp eye upon punctual running. Various influences tend to delay a train, and when the cumulative delay exceeds a certain limit, it is necessary to ascertain the whys and wherefores with a view to the elimination of the causes if at all possible. At certain stations the driver, if his delay amounts to two minutes or more, is called upon to leave a brief explanatory report; while, by the aid of the telephone, the traffic controller can pick up a lagging train at any station to proffer his "Please explain!" across the wire.

A detail which contributes to efficiency and service, and which leads to smooth working from the official and public points of view, are the automatic indicator boards notifying the destination or routing of approaching trains. They are informative both to the signalmen controlling junctions and other points, and to the passengers on the platform. The operating principle of this device, also dependent upon electricity, though apparently intricate to explain, in reality is simple in working.

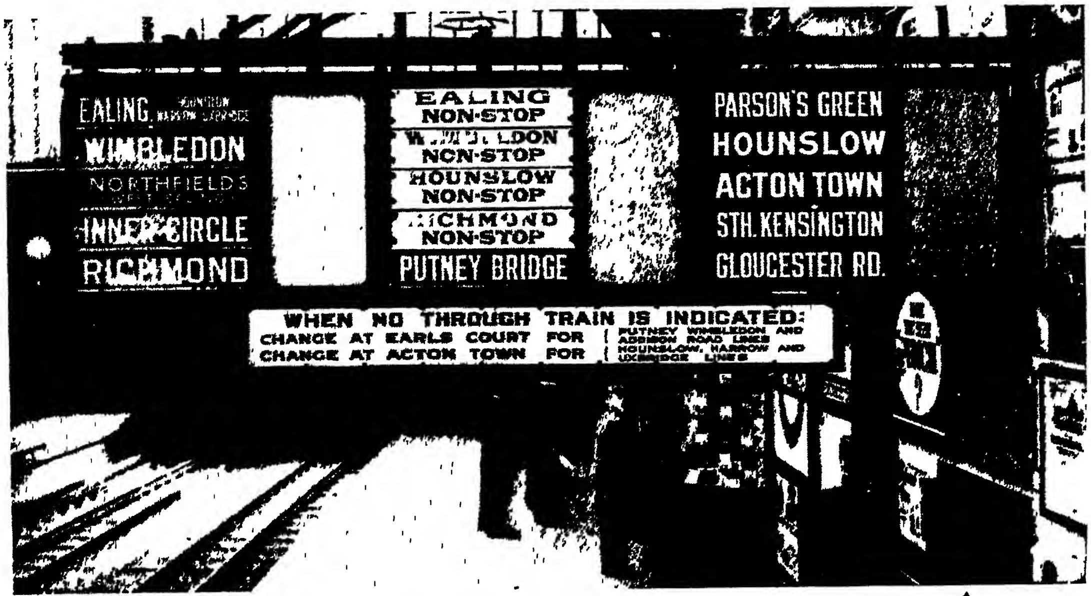
The signalman at the end of the line—in this instance the term "line" indicates a section free from junctions or crossovers, such as that between Mansion House and Sloane Square stations upon the District—as each train departs, dispatches its destination, which may be



PUNCTUALITY IS THE SOUL OF RAILWAY EFFICIENCY.

Headway clock at a tube station, indicating to the motor-man the time interval separating him from the preceding train. Each figure corresponds to one minute, while quarter-minute intervals are indicated between.

any one of those shown on the sign (see page 292). These descriptions are received and stored at each station in the section concerned, to be shown upon the large sign spanning the platform in their correct sequence. The indicator favoured by the District—the basic principle is



WHERE DOES THE NEXT TRAIN GO?

Electrically-operated indicator board giving the route and destination of the next train. When it leaves the station the indication relating thereto is automatically cancelled, and the following train indicated. At some stations upon the District Railway, as at St. James's Park, the descriptions and destinations of three consecutive trains are indicated in sequence and simultaneously upon the railway "signpost." The receiving apparatus shown on page 293 is housed in a small cupboard on the wall below the indicator board—marked in the photograph by the arrow. All these devices for this section are actuated from main signal cabins at the Mansion House and West Kensington.

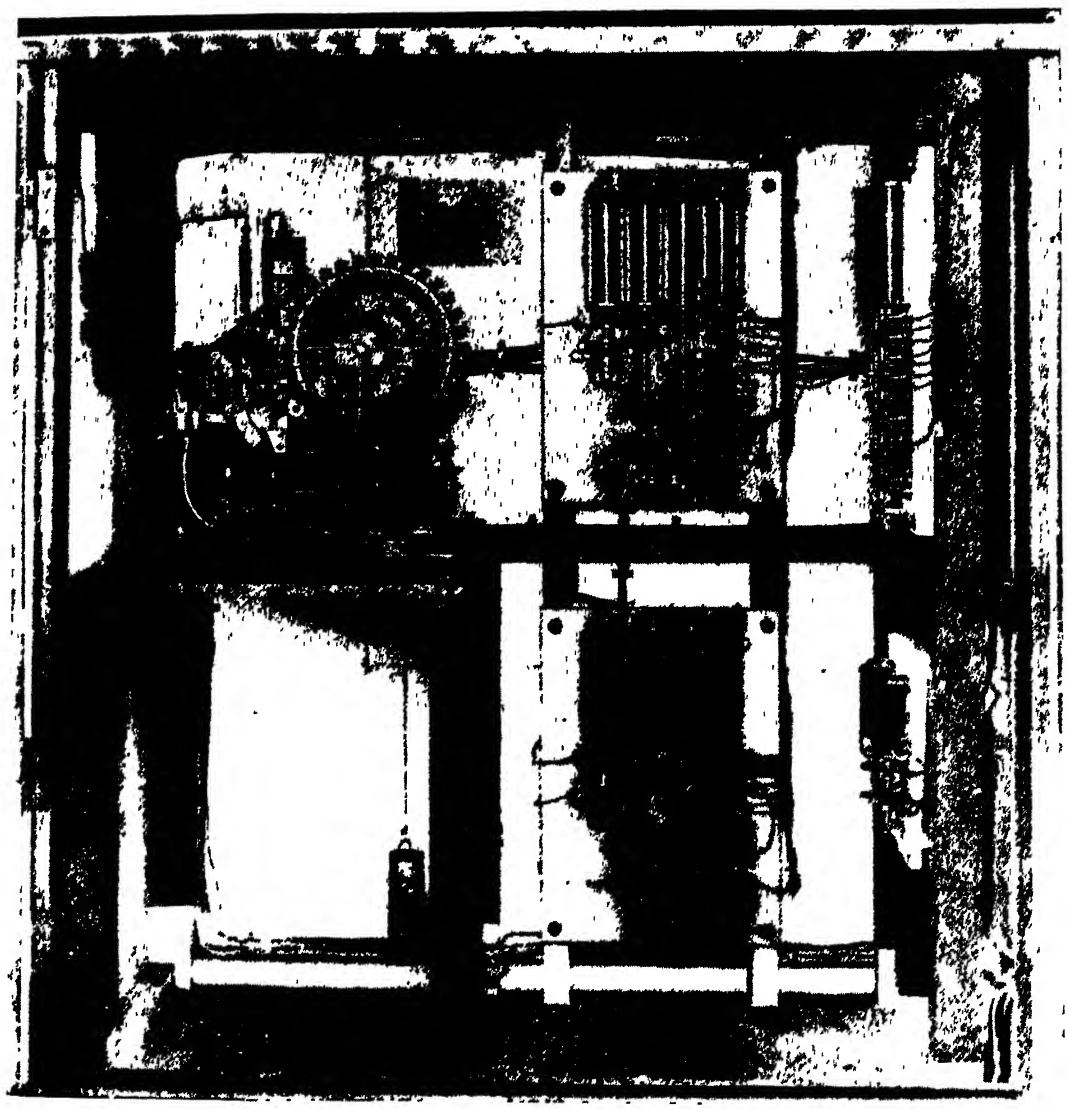
adopted on the Metropolitan—gives the route of the train together with its destination. When the train passes out of the station the description applying thereto is cancelled, and the next train is indicated. The descriptions are transmitted from one end of the section to the other by four wires only, and for reference purposes these wires are lettered respectively "A," "B," "C" and "D." By arranging suitable combinations of these letters fifteen different descriptions can be obtained and given.

The descriptions are launched by the signalman operating a transmitter. This comprises a disk of ebonite having brass segments set in specific positions upon its face. This disk is free to revolve, and is fitted with a handle and pointer outside the case for its rotation. Four contact springs, one connected to each wire or line, are so arranged as to press against the face of the disk, and, as the latter is rotated, these springs come into contact with the brass segments at various points during the revolution. On one side of the case is a lever which, when pulled, moves a switch, and allows current to pass to the brass segments on the disk, and thus to any of the springs which may be in contact therewith. The signalman turns the handle until the pointer comes opposite the description of the train he desires to dispatch. He then pulls the lever, and in this way current is permitted to flow through the segments and springs to the combination of wires corresponding to the description.

At the other end of the circuit is a receiver for collecting and storing the descriptions until they are required. This receiving apparatus consists of a metal drum, mounted upon bearings to facilitate revolution. Around the periphery of this drum are disposed a number of studs arranged in rows of four each across the face of the drum. Beneath the drum are four electrically-operated hammers, one connected to each line or wire. When these hammers become

energized by the current dispatched from the sending station, they strike on the corresponding studs above, knocking them inwards. The studs remain in this depressed position until they are released, when the drum is free to revolve one step—the distance between two succeeding rows of studs—to bring another set of the studs above the hammers, when the cycle of operations is repeated.

Inside the drum are four springs so arranged that they establish contact with those studs which are depressed by the falling hammers. In this manner the current received across the wires is transmitted by the hammers and their corresponding studs through the springs to the "combinator," where the combinations are sorted into their various descriptions. This apparatus is an arrangement of four coils, each having an armature fitted with a large number of contacts through which



HOW THE TRAIN INDICATOR WORKS

Receiving apparatus, actuated from the signal box, showing revolving wheel with projecting studs which are depressed by electrically-operated hammers. By the electrical connexion thus established the indications upon the board are given. The relative positions of the cupboard containing the above electrical equipment and the indicator board is seen in the illustration on page 292.

electrical circuits are arranged, according to the combination of coils energized and de-energized. In this manner the desired description is formed and transmitted to the destination board, illuminating the sign to which the combination conforms, and consequently giving the description of the succeeding train. When the train leaves the station the collector springs are automatically moved forward to the succeeding row of studs; the cancelled studs are released and the description of the outgoing train extinguished upon the indicator board. The arrangement is such as to permit modification within wide limits. The receivers actuating the indicator board at some stations, notably those between the Mansion House and Sloane Square stations, are fitted with three sets of collector springs, and these combinators accordingly indicate the destination of the next three approaching trains in sequence and simultaneously.

Undoubtedly the most arresting feature of the operation of such an electric system as the Underground railways of London is the fluctuation in the demand for electricity as imposed by the traffic.

The Fluctuating Load-Graph

A typical day's graph is shown in the illustration opposite. At 2 a.m. the pen is resting on the 3,600-kilowatt line, and for the first two hours it hovers between the 2,800 and the 4,800-kilowatt marks, these variations coinciding with the volume of official movement and work in the tunnels. At 4.0 a.m. the pen sets out upon its climb of the calibrated paper. By 5.0 a.m. it has reached 7,600 kilowatts, but in fifteen minutes the demand is nearly doubled. The 22,800-kilowatt line is reached by 6.0 a.m., and the 36,800-kilowatt line at 7.0 a.m.

Now comes the biggest forward leap of the early hours; 47,200 kilowatts is reached by 7.15. The rush to the City has begun. At 7.30 the 50,000-kilowatt mark is reached, to drop immediately to 42,800 kilowatts: at 8.0 a.m. there is a jump to 52,800 kilowatts. For an hour the load oscillates between this figure and 45,200 kilowatts; the nine o'clock stampede swings the pen up to 54,400 kilowatts—the peak-load. So far as the system drawing upon the Chelsea power-station is concerned, the pen now begins to slip downhill.

In this instance the fall from 10.15 was persistent. For the next three and a half hours the load never rose above 34,000 kilowatts, while at 12.30 it receded to its lowest level for the day—28,800 kilowatts. Had some notable passing event occurred between the hours of 10 and 2, some violent swinging of the pen, caused by the movement of the world and his wife, would have resulted.

Symptomatic of Londoners' Habits

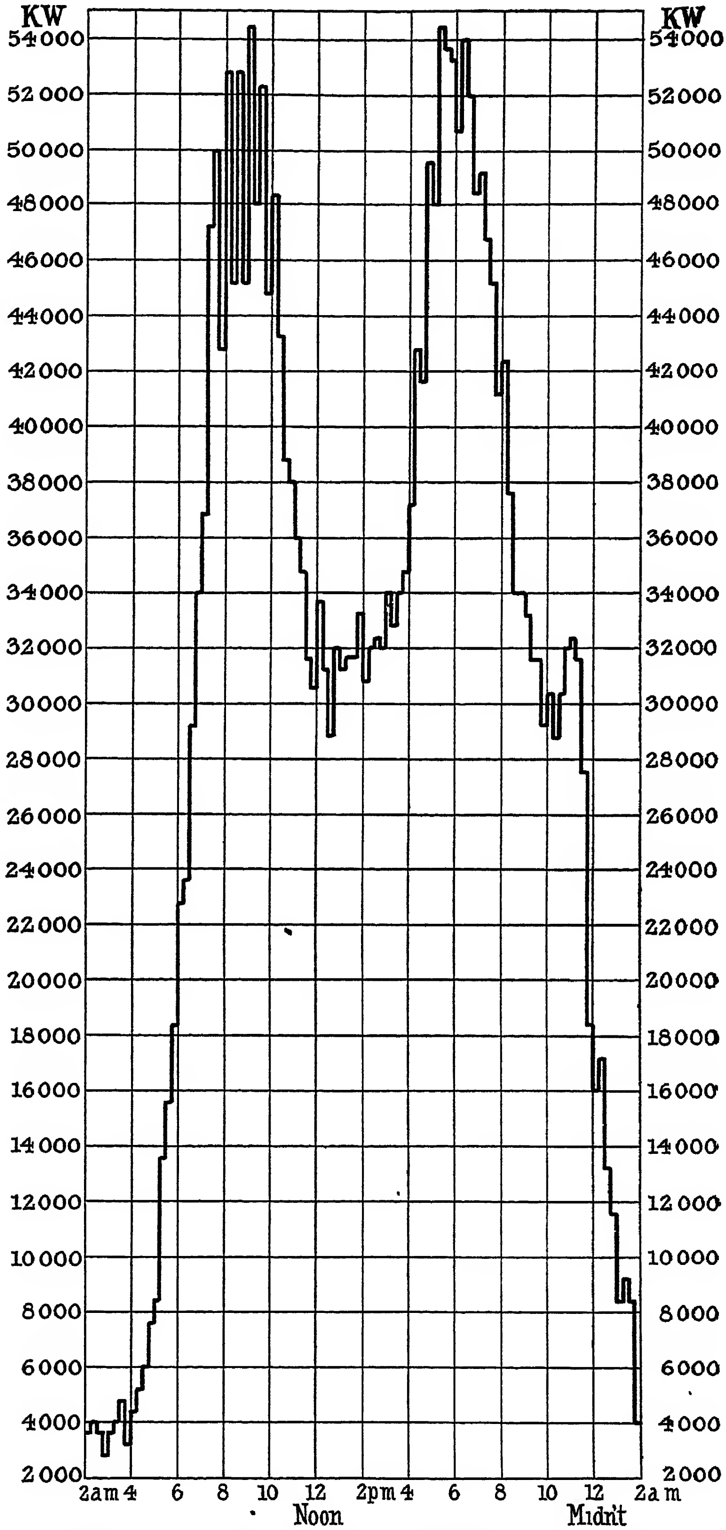
At 3.30 p.m. the pen rested at the 32,800-kilowatt level, but shopping London began to assert its significance, while the first to cease labour for the day had commenced the homeward trek, which, by 4.45, was in full swing. At 5.15 the pen touched its zenith—54,400 kilowatts—for the second time during the day. The first wave of those who leave their offices about five o'clock is carried homewards in about three-quarters of an hour. Then there comes the six o'clock stampede. The final fall sets in rapidly, to give an upward flicker to catch those who set out for their homes at seven o'clock.

As this graph shows, the daily invasion of the metropolis is conducted in a manner vastly different from the evacuation, because very large numbers of the City's toilers commence work from 7.30 to 8 a.m. Still larger numbers have to be at their desks by 8.30 and 9 a.m., but the great majority do not reach their offices until from 9.30 to 10.

Again, one and all appear to cease labour at approximately the same time, so that transportation has to be compressed into about two hours in the evening. Once the exodus commences in grim earnest, it

continues much more solidly than the invasion, because, during the evening rush, in the case in question, the demand did not sink appreciably below the 51,000 kilowatts level, whereas during the morning it oscillated somewhat violently between 45,200 and 54,400 kilowatts. During the evening two hours' rush there will be as many as 82 trains on the Metropolitan-District, as well as 130 trains on the Tubes in simultaneous movement —212 heavy trains moving over 63·75 miles of track. One and all are charged to their utmost capacity with human freight borne homeward as rapidly as electrical energy, combined with safety, will permit.

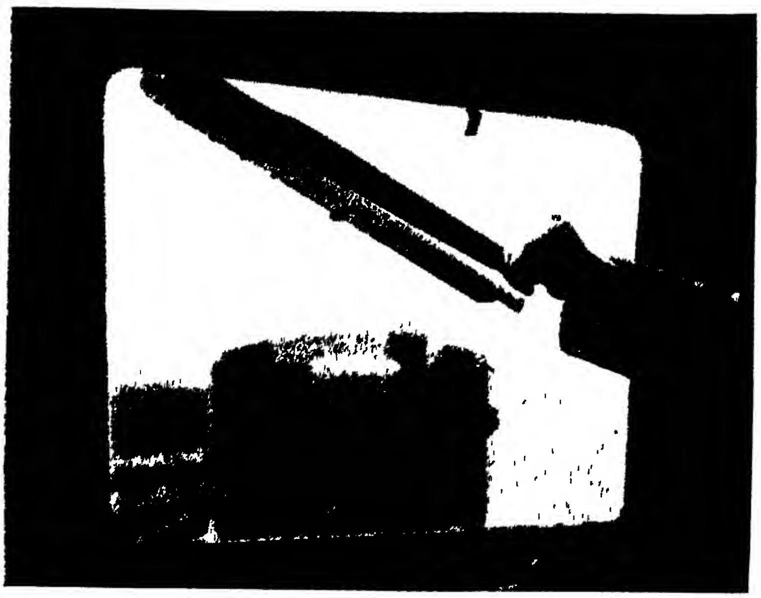
Before 7 p.m., the back of the day's transportation task is broken. The pen of the graph swings rapidly downwards, but not to rest; far from it. Before 8 p.m. is reached there is a short, sharp and slight spurt upwards, due to the traffic of the theatres and general relaxation. This is only a passing phase, not lifting the pen beyond the 42,400 kilowatts mark, and is followed by a dramatic heavy slump in the production and consumption of the kilowatts, the pen receding to below 29,000 kilowatts just after 10 p.m. There is another short, sharp rise to 32,400 kilowatts indicating the power-demand to cope with the returning



HOW THE ELECTRIC POWER IS ABSORBED BY TRAFFIC.

A representative twenty-four hours' graph of the demand upon the Chelsea power-station. It will be observed that the maximum demands for current are incurred between the hours of 7 and 10 a.m. and 5 and 6.30 p.m.

theatre-goers. This rush—the dying kick in the day's operations—registers its peak-load at 11 p.m., and is soon over, permitting the pen to swing still farther down the calibrated paper in big strides until midnight, when the belated Londoner hurries from his club and supper, to make certain of Underground transit to his residence, thereby slightly arresting the descent of the pen. This is promptly overcome, and the pen hurries downward as rapidly as it gracefully can until 1 a.m. Here comes a final slight upward movement to satisfy those who delay their homeward flight until the last moment. With the "switch-off," otherwise closing of the railways for the day, the pen sweeps to the 4,000-kilowatt level, where it settles down to its restful recording of the minimum power demand for the twenty-four hours.

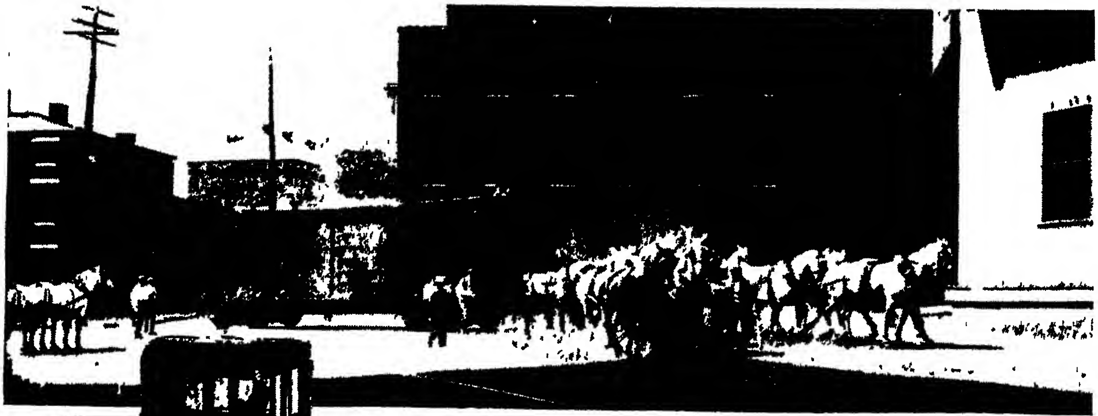


A CLEAR LOOK OUT FOR THE METROPOLITAN MOTOR-MAN IN DIRTY WEATHER.

The ingenious window-wiper which is operated from within the cab by the driver.

The study of such a load-graph in connexion with the Underground railway traffic of the Heart of the Empire is a fascinating mirror of the social, commercial and manufacturing life and habits of its citizens. It betrays their methods and foibles, *en masse*, in a somewhat unfamiliar manner. Incidentally, if the graphs for every day of a complete year are investigated, one can almost read the weather variations as if they had been registered by a barometer. The wet and foggy days stand out with startling prominence.

Interurban travelling London consumes, upon an imposing scale, a commodity of which it is probably ignorant. At the Chelsea power-house the 260,000 tons of coal are passed in an endless stream through the furnaces to be converted, via steam, into 255,000,000 kilowatt-hours during the twelve months. Where does all the power go? This is the inevitable inquiry. Obviously the running of the trains is responsible for the heaviest consumption, but there are other and just as voracious details of the intricate fabric. Analysis reveals some interesting appetites so far as electricity is concerned. An average week's power consumption on the District and Tubes may be set down at 3,250,000 units; of this total, traction will take the lion's share, or a round 3,000,000 units. The lifts and escalators exact the next heaviest toll—some 110,000 units. Then comes illumination, which cannot be satisfied with less than 75,000 units. The signals contrive to do away with 43,000 units. The balance is absorbed by a bewildering array of electrically operated devices. Individually their consumption is negligible, but in the aggregate they present a somewhat imposing total of about 22,000 units. The British metropolis has the distinction of holding many wonderful world's records, not the least of which is the electrical movement of its citizens.



HARD WORK FOR HORSES.

A double-string team—16 animals—hauling a heavy loaded box-car from factory to railway sidings via the streets. *Inset:* Contrast the novel electric tractor, with drive on all four wheels, built by the Pennsylvania Railroad to supersede horses in this work. It cost £2,680.

A Novel "Electric Horse"

A HAULAGE MOTOR WHICH HAS DISPLACED THE CUMBERSOME—IF PICTURESQUE—TEAM OF HEAVY HORSES.

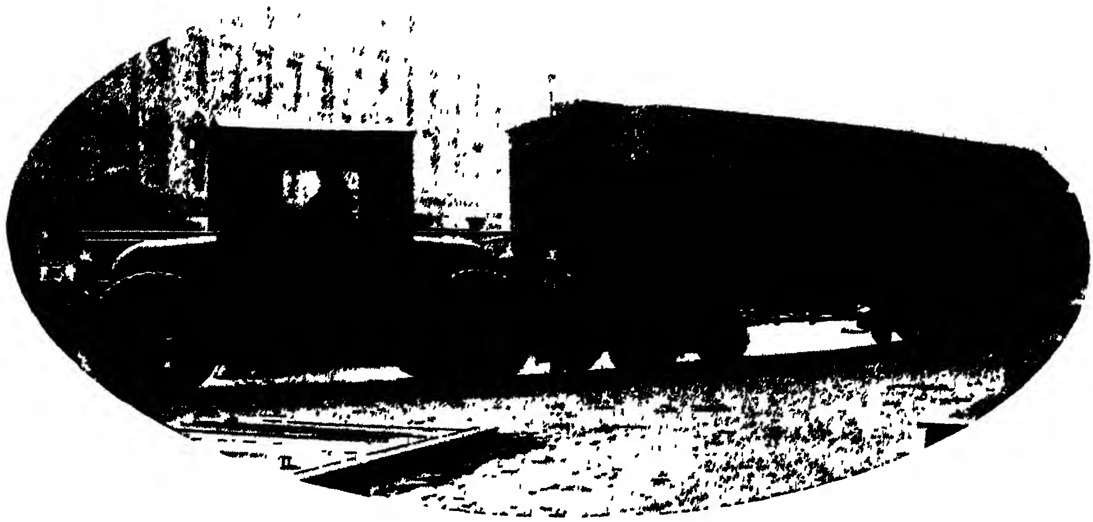
THE movement of railway trucks and wagons in the vicinity of docks, and to and from the sidings of large factories, has always been a perplexing problem. Locomotive haulage encounters objection owing to the risk presented to other users of the highways which have to be crossed, or traversed, while such vehicular movement is far from being an economical method. In Great Britain, where the use of locomotives for this purpose through the public streets is severely deprecated, the practice is to move goods between the factories and the railway stations by horse or motor-vehicles, thereby involving intermediate handling with its concomitant increase of costs.

Upon the American continent the problem is even more acute. In Canada and the United States the factories often constitute the cradle of a new community, and, when established, no objection to the extension of tracks from the railway to the factory can be raised, because no one is endangered or inconvenienced. It is only when the town develops that the danger factor arises, because under the new conditions the tracks traverse, not open land, but traffic-carrying public highways. To meet the situation special locomotives have been designed for such service, but their use has generally provoked such hostility as to compel their speedy withdrawal. The alternative—horse-haulage—then has to be introduced, and despite the enormous advances effected in mechanical traction, the animal still reigns supreme in this field.

But animal power is expensive; the price paid for such work is out of all proportion to the service rendered. The

American freight car is heavy and cumbersome, and as the weight factor is steadily increasing, the demand upon animal effort is persistently rising. To-day, the general practice is to use a string-team of eight horses for the movement of a single vehicle, and the length of such a team is about 70 feet, while the tractive effort is insignificant. But this is not the only objection. The horses have to be selected curves of 50-feet radius and grades of 1 in 50 have to be negotiated. Experience showed that there was no existing type of mechanically-propelled vehicle capable of meeting the situation, so the consulting engineer designed a tractor solely for this range of work.

The resultant vehicle possesses many novel features. Electricity was selected as the motive power. An immense draw-

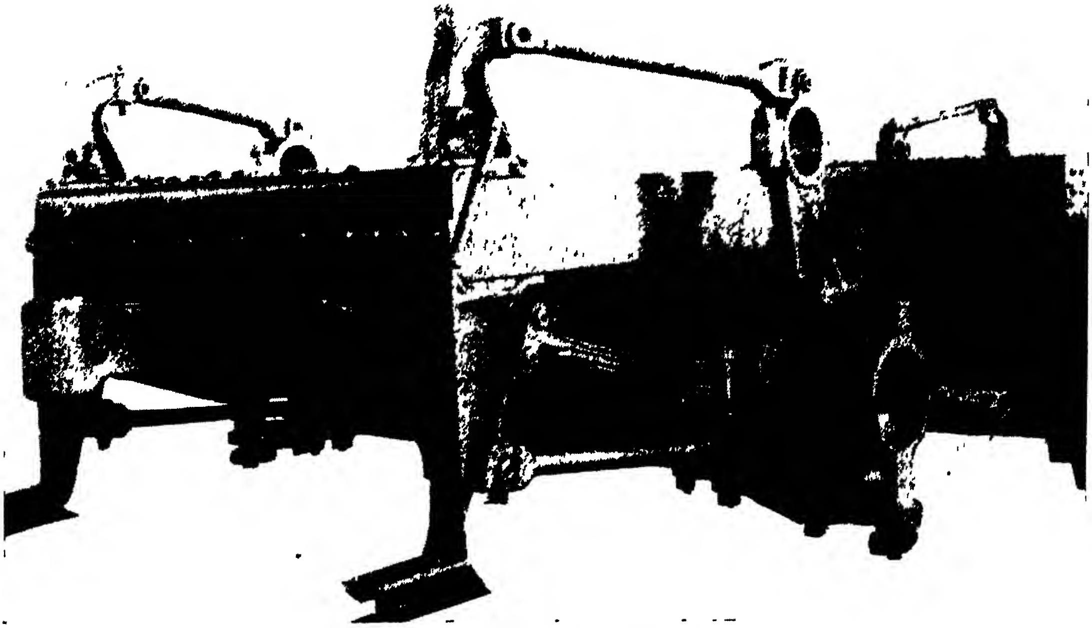


ROUNDING A STREET CORNER.
The tractor is designed to describe a curve of 50-feet radius, and is capable of hauling trains running up to 300-400 tons dead weight.

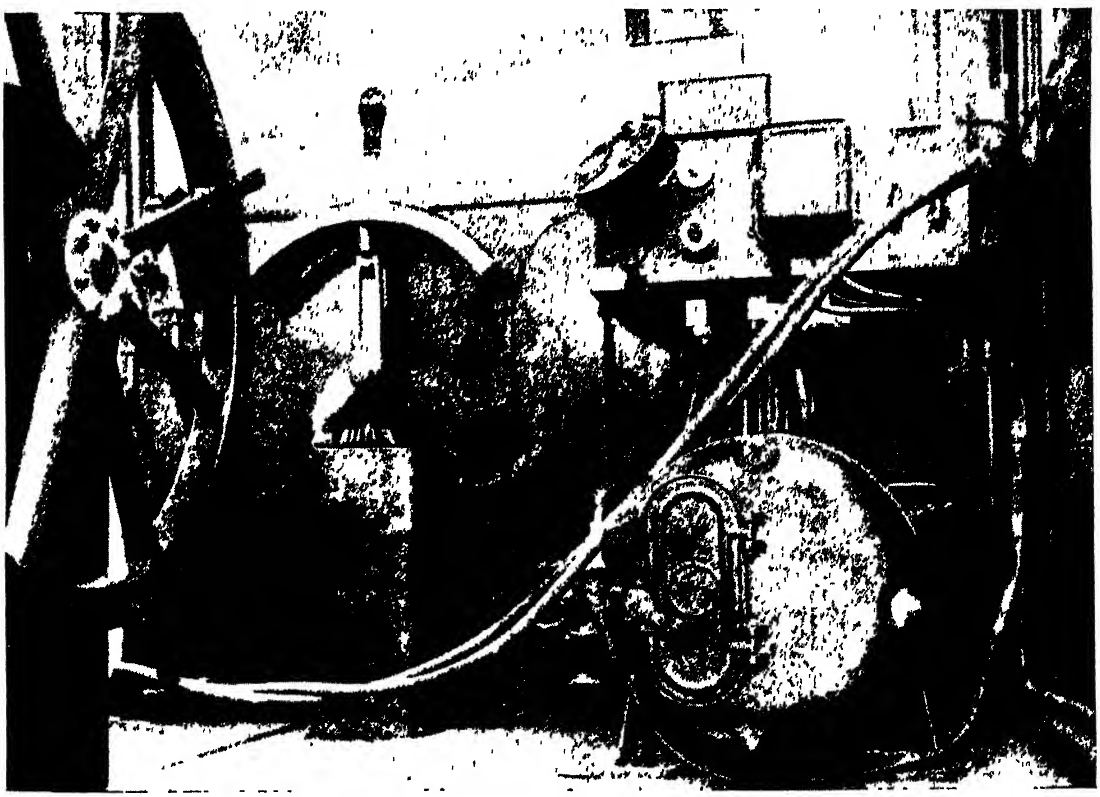
with extreme care. They must be heavy, slow, steady, easy-going and intelligent. The duty is arduous and exacting, and suitable animals are expensive in first cost, while their useful life is brief and uncertain. If the animal be temperamentally suitable it can be steadily employed for about four years; if spirited its span of usefulness may be less than twelve months.

The situation became so acute that at last the Pennsylvania Railroad decided to make a determined effort to secure emancipation from the horse for this work. A well-known engineer, Mr. T. V. Buckwalter, was requested to solve the difficult problem if he could. Often a loaded car represents a dead weight of 30 or more tons, while

bar pull being imperative, all the four wheels, 60 inches in diameter, are drivers, are also steering-wheels and are effectively braked. The frame is built of steel, and carries a centrally disposed commodious cab, flanked on either side by a bonnet carrying the mechanism. The vertical steering-wheel, of the marine type, is set in the centre of the foot-plate to permit operation in any direction with equal facility. Steering on all four wheels permits the tractor to turn in a circle of 20-feet radius. The controller and brake-lever, in duplicate, are mounted on each side of the vehicle, within convenient reach, to allow the driver to manipulate the steering-wheel with the one hand, and

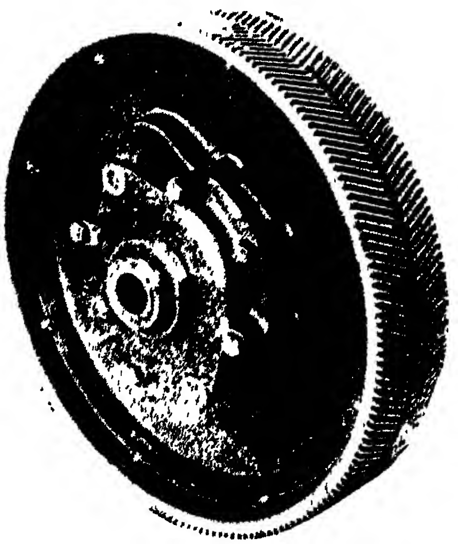


THE CHASSIS OF THE TRACTOR
End view, showing massive construction.



THE CONTROL OF THE "ELECTRIC HORSE."
Interior of cab showing, at left, vertical steering-wheel and, at right, under switch-board, motor-driven air-compressor for the operation of the Westinghouse brakes acting on all four wheels.

the controller and brake mechanism with the other. As automatic air-braking is installed on all four wheels the cab also carries



THE HEAVY COUNTERSHAFT GEAR
It measures 31 inches in diameter by 6 inches across the face, and has herring-bone teeth.

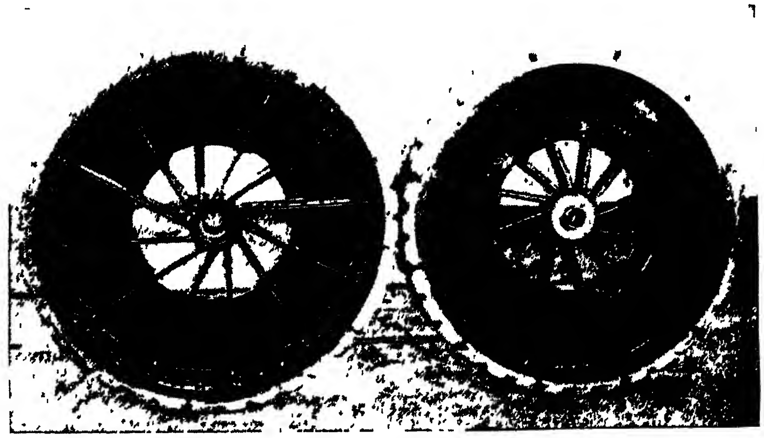
the air-compressor, driven by an electric motor with switch control, for charging the air-reservoir of 15 cubic feet capacity to a pressure of 90 to 95 lb. The braking system is so designed as to render it impossible to use motive power while the brakes are applied.

Construction is simple and substantial to minimize the risk of break-down. The motor-equipment comprises two 20 - horse - power series-wound motors for 85 volts and 60 amperes at 900 revolutions per minute. The power is transmitted through a flexible coupling, herring-bone gears giving a reduction of 40 to 1, split countershaft, and universal pinions to the driving-gear, which is bolted to the casting of each of the four wheels. The differential gear, carried in the countershaft housing, embodies a new principle; there are only four moving parts. The efficiency of this differential is very high; there are no losses in the transmission of the power from one side to the other, or in the thrust bearings.

The controlling apparatus gives three symmetrical speeds in either direction. The first speed is for very slow running and backing; the second speed, 3 to 4 miles an hour, is for use in heavily congested yards or streets; the third, for normal running, has been set at 6 miles an hour, which permits the tractor, with its attached load, to pull up in 6 to 10 feet.

The electric energy is drawn from a battery of 80 Edison cells, weighing 4,350 lb., of 450 ampere-hours capacity—90 amperes for 5 hours—carried under the floor of the cab for accessibility. About 16 miles can be covered on a single charge, but this performance must not be compared with that of the ordinary electric vehicle owing to the vast difference in the character of the work. This tractor is often called upon to handle loads up to 30 tons upon grades of 1 in 50, while, at times, upon such a bank it is coupled to trains ranging from 300 to 400 tons in weight.

The vehicle, which cost £2,680, weighs



DRIVING-WHEELS OF THE "ELECTRIC HORSE"
Each measures 60 inches in diameter, has tangential spokes, special type of block tire, and gear-wheel bolted to inner face.

28,850 lb. The normal and maximum draw-bar pulls are 8,000 lb. and 21,500 lb. respectively. The overall length of the tractor is 23 feet; width 8 feet 4 inches; wheel-base 12 feet 6 inches; tread from centre to centre of wheels 7 feet; width of tires 12 inches; and overall height 11 feet 3 inches.

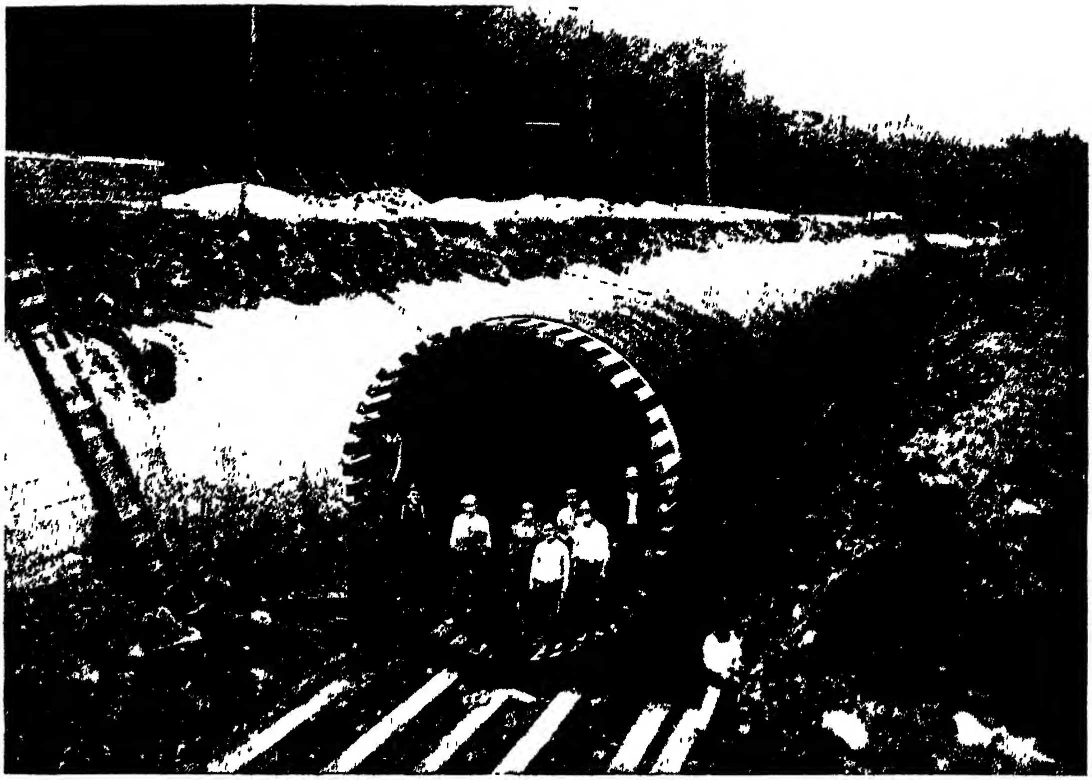
It has proved remarkably economical in operation. During the first seven months' duty in the New Jersey express yards of the railway it covered 2,076 miles, and moved 4,935 cars representing 165,574 tons involving 2,789 movements, in 1,361 hours. Only nine working days were lost for repairs. The total cost of operating the tractor during that period, inclusive of all charges—capital, maintenance and operating—was £925. Had horses been engaged for the selfsame volume of work they would have cost £1,836—an advantage of £911 in favour of the tractor.

To determine the precise possibilities of this unit a novel test was conducted in the railway shop-yards at Juniata. A locomotive and two heavy trucks were coupled to the tractor, and to general surprise it pulled this dead load with remarkable ease. It was then decided to conduct a "push-of-war" between steam and electricity. The locomotive was brought to bear against one end of the trucks, and the tractor against the other. The drivers of the two machines were told to let themselves go one against the other for all each was worth. The driver of the locomotive threw his throttle wide open, and although his engine was rated at 21,500 lb. draw-bar pull, he failed to hold his own—the electric tractor forced the steam-locomotive and trucks back several feet. This achievement revealed the immense power of the tractor in no uncertain manner.

From the humanitarian point of view this pioneer "electric horse" will be appreciated. Dragging railway wagons to and fro imposes terrific wear and tear upon animals. At the same time the mobility of the tractor in either direction independently of any track, and its simple control, conduce to the safety of all concerned, whether they be working in conjunction with the railway vehicles or utilizing the highway in the conduct of their normal affairs.

A "PUSH-OF-WAR"—ELECTRICITY *VERSUS* STEAM

For a trial of strength the Pennsylvania electric tractor was attached to one end, and a steam-locomotive to the other end of two coupled trucks. The drivers of the two power-units were instructed to push one against the other for all each was worth The electric horse won. Although the steam-locomotive went "all out," it was forced backwards several feet.



A HUGE WOOD-STAVE PIPE-LINE UNDER CONSTRUCTION
The third conduit being laid by the Hydro-Electric Power Commission of Ontario at Niagara Falls. It is 13½ feet in diameter. To the left may be seen the bared wall of No. 2 conduit, 18 feet in diameter and built of ferro-concrete.

Wonders of Pipe-line Construction—II

HOW THE ENGINEER HAS SOLVED THE PROBLEM OF CONDUCTING WATER FROM HIS STORAGE RESERVOIRS TO THE DISTANT POWER-STATION

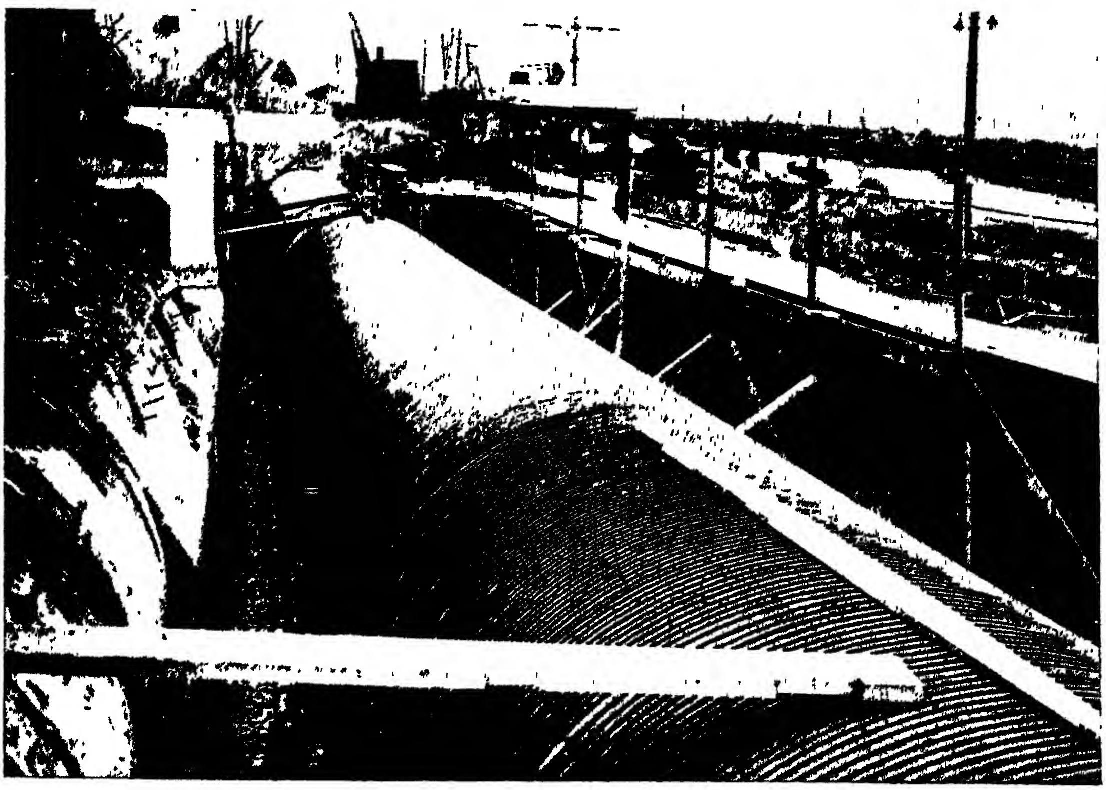
WHILE tunnel, canal and flume constitute favoured forms of leading the harnessed water from the reservoir to the fore-bay to feed the turbines, it is the pipe-line which is most freely utilized for this duty. Some of the lines which have been laid constitute audacious and impressive examples of the engineer's prowess in this privileged field. Both wood and metal are employed for this purpose. The possibility of wood being used as a pipe-making material may seem somewhat strange, and scepticism may perhaps arise as to its suitability, at least in a permanent sense, for such service; but, and this may be equally surprising, it is doubtful whether a scientifically built wooden pipe-line, so long as the ruling climatic and other conditions are favourable, can be excelled by metal.

When first introduced in this capacity the wooden lines were of relatively small diameter, but as the engineer essayed greater achievements in the controlled movement of water for power, so did the

master minds in wood-pipe design and construction keep pace with his progress. When big diameters for these lines first became established, the opinion prevailed that there was nothing like iron or steel for such duty, but this conviction has undergone considerable modification during recent years, especially as the wooden line has proved able to stand up to work which a few years ago would have been considered to be quite beyond the capacity of timber.

The wooden pipe has much to commend it; equally it suffers from certain inherent defects. The latter, however, are well known and so can be effectively avoided. In the western districts of the United States and Canada, where the timber flume is very frequently seen, the wood pipe is an equally familiar feature, but it must not be inferred that such use of timber is confined to that part of the world; far from it. Wooden pipe-lines are quite common in Australasia, while one of the most important and largest power pipe-lines essayed during recent years was carried out in wood in preference to steel, and that in a district where metal has always held sway.

Timber first commanded recognition for this purpose in the western stretches of the American continent, for the simple reason that it was cheaper than metal. The woods best adapted to the duty, namely, Californian redwood and Douglas fir, grow profusely upon the flanks of the coastal mountain range, whereas there is no local iron and steel industry; these metals have to be hauled across the continent. Thus economic considerations demanded the submission of wood to a practical trial, and, as it did not prove wanting, it has not



THE HUGE WOOD-STAVE PIPE-LINE COMPLETED

It is formed of 95 staves, each measuring 6 inches wide by 4 inches thick, disposed in a circle and secured in position by steel binding rods. This conduit, one of the largest wrought in wood, is 6,700 feet in length, and brings down water for the development of 40,000-50,000 horse-power in the extension to the power-house of the Ontario Power Company.

yet been superseded, certainly not up to specific diameters, although there is little disparity now between wood and steel so far as diameter of the pipe is concerned.

The wood pipe-line is built of planks or staves disposed in a ring, with the thickness and width of the integral units varying according to the diameter of the pipe and its designed duty. Construction is carried out along quite distinctive yet simple lines. If one visualizes a continuous barrel, of uniform diameter, under assembly, one can form a conception of a wooden pipe-line under construction. The planks, or staves, are laid side by side in the ring conforming with the diameter required, a circular template assisting this part of the work. The staves are laid edge to edge in the longitudinal direction, care being observed to see that the ends are staggered, that is to say, do not come in the one vertical plane.

As the staves are placed side by side, so are they disposed end to end, butt against butt. The method of executing a tight connexion in the two directions is distinctly ingenious. Along the one edge of each stave a metal bead is run which, when the staves are cinched-up tightly, cuts into the plain flat wooden edge of the adjacent stave, thus forming a tongue and groove joint. The butts are connected by dowels. When first introduced wooden dowels were used, but it was found that when the water was admitted into the pipe and soaked into the dowel, the latter expanded and split the end of the stave. Accordingly iron dowels are now used.

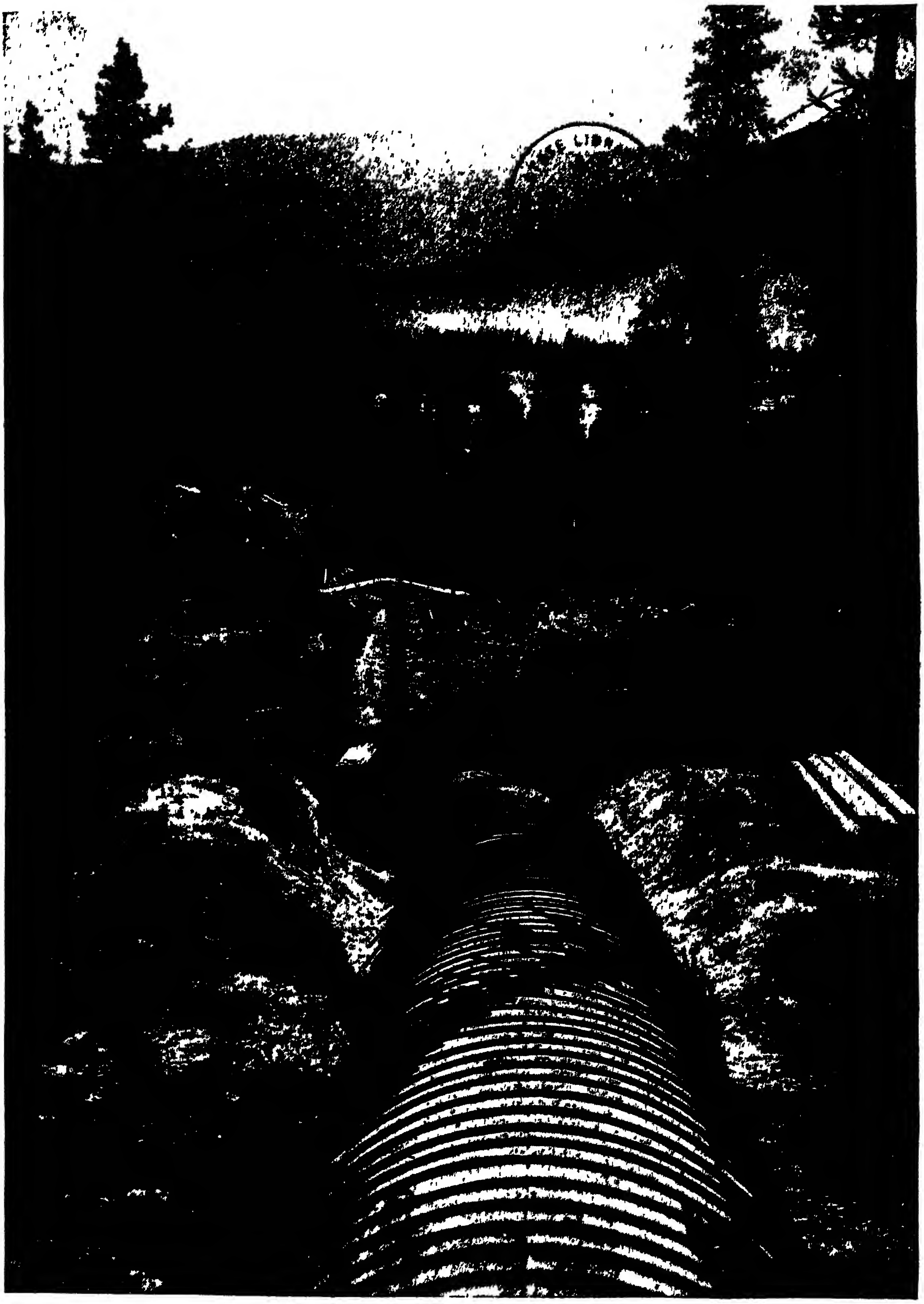
Cinching-up the Staves

As the staves of a barrel are held firmly and immovably in position by the iron bands, so are the integral members of the pipe-line firmly secured in place by hoops or binding rods. A round steel rod is bent to the curvature of the pipe. One end of this rod is permanently secured to an iron casting or shoe which is also bored to allow the second end of the rod to pass through it. The rod is passed round the pipe, the face of the shoe, owing to its shape, bedding flatly upon the outer surface of the staves. The free threaded end of the rod is passed through the hole in the shoe, and a nut is screwed on.

The ring of staves is set up side by side and the hoop is partially tightened up, which brings the staves into the designed circular position. The members are then driven home longitudinally one by one, with a maul, thus causing the dowels to establish a complete and tight joint at the butts. The hoops are now tightened or cinched-up. This tightening forces the metal bead, carried along the one edge of each stave, to bed itself deeply into the wood face of the stave alongside. Cinching-up is continued until further tightening is impossible. The binding rods are set a certain distance apart, the space varying according to the diameter of the pipe and the internal pressure or bursting strain imposed by the water within. The circumstance that the pipe can be kept tightened up to the utmost capacity by means of the hoops is a distinct advantage, but the effort thus expended is supplemented by another force. When the water is admitted and the wood becomes saturated it expands, and this tends to drive the metal bead more deeply and tightly into the adjacent stave, and the greater this expansion the tighter the joint becomes, thus rendering leakage impossible.

Water Completes Tightening Process

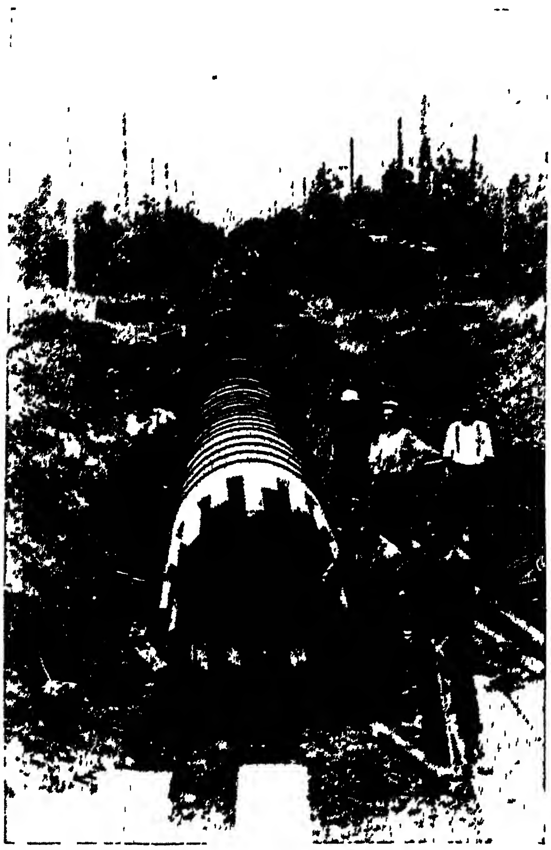
The one outstanding disadvantage of the wooden stave pipe is the difficulty of adapting it to the undulations of the ground should the latter be very pronounced. The material is not so flexible in this respect as the metal, of which shorter and smaller integral sections can be used according to the curvature imposed. The minimum radius of the curve which can be described by



THE WOODEN PIPE-LINE WINDING ITS WAY UP-HILL AND DOWN-DALE.

While wood is not such a flexible material as steel, the hydro-electrical engineer can carry such a conduit over scarred mountain slopes. The pipe-line shown in the above illustration leads the water across country to one of the numerous power-plants established by the Pacific Gas and Electric Company among the Cascades, and shows how the staves are "cinched-up" by the circular binding rods.

a wooden pipe of 52 inches in diameter is about 240 feet. Accordingly, if the ground be badly broken, or seared with watercourses, the pipe has to be supported up to the minimum permissible radius. Similarly, in the horizontal plane such sharp



A 50-INCH WOOD-STAVE PIPE-LINE IN THE MAKING. This form of conduit is much in favour upon the Pacific coast. The above line, 3,170 feet in length, leads the water to the turbines of the power-plant of the Dunsmuir Collieries, upon Vancouver Island.

curvature as is possible with metal cannot be attained. These deficiencies, if such they may be called, are known, and consequently, the engineer, as a rule, can devise ways and means to meet them; but where straight lengths of line are to be laid the wooden pipe has no equal. It is cheaper than its metal competitor up to certain diameters. If the dimensions and internal pressure be raised to an advanced degree, rendering it necessary to place the binding rods close together, it is quite possible that the amount of metal thus introduced might be equal to the weight of a metal pipe for equivalent service.

The staves have to be carefully selected and prepared; the grain must be straight. The staves are planed on all four sides, and the facing thus imparted is always preserved. A wood pipe will always remain true and does not deteriorate like one fashioned from iron. Wooden pipes of large diameter, which have been in constant service for ten years or more, when opened up, have proved to be as sound as upon the day they were laid. One might conceive that a wooden pipe would be susceptible to decay, but so long as the pipe is kept full of water and the saturation of the wood is complete, rotting will not develop. All things considered, it is now conceded that the life of a wooden-stave pipe is longer than one of iron, while the circumstances that it can be tapped easily, if desired, or repaired, are other features in its favour. To-day, it is by no means uncommon to find wood, steel and concrete in company; each sort is selected for the particular range of service to which it is best adapted, because it is a relatively easy matter to connect the various sections to one another, despite the wide dissimilarity of the materials.

At the hydro-electric undertaking built for the Dunsmuir Collieries, reference to which has already been made in connexion with the timber flume, the water moved by the latter is subsequently taken up by a wood-stave pipe, 96 inches in diameter, and 4,500 feet in length. This conducts the water from the pipe-line intake to a **Y** structure where the one stream of water is divided to be carried over the next step in its journey, 4,500 feet in length, through two wood stave pipes, each 72 inches in diameter. At the moment only one pipe has been laid, but the second will be built when exigencies so demand. This

72-inch pipe-line carries the water to a structure whence extend four outlets, each connected to a pipe-line 50 inches in diameter. Only two of these lines have so far been constructed, and they are of wood staves carrying the water a further 3,170 feet, where they form a junction with steel pipe-lines conducting the water over the final 660 feet to the power-house. In this instance, therefore, wooden pipe-lines are employed to carry the water over a total distance of 12,170 feet in three stages through pipes of 96, 72 and 50 inches diameter respectively.

Details of a Large Pipe

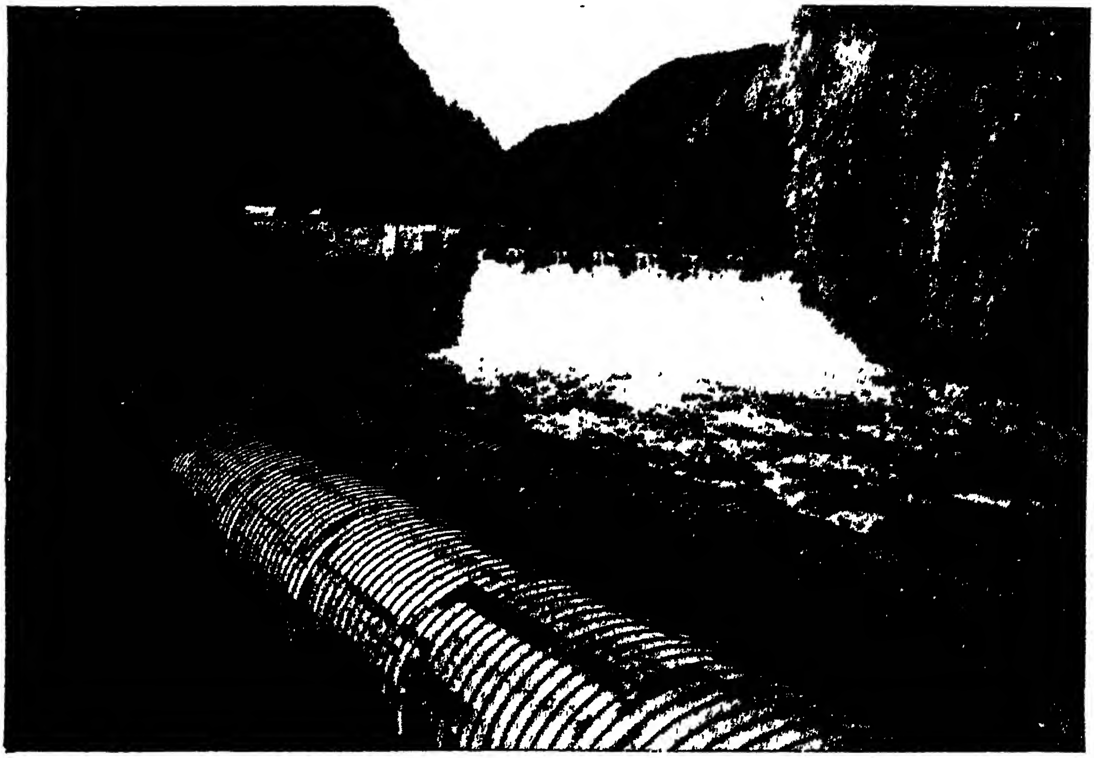
The largest pipe is built up of 58 staves disposed in a circle, each stave measuring $5\frac{9}{16}$ inches wide by $3\frac{9}{16}$ inches thick. The 72-inch pipe is made up of 43 staves measuring $5\frac{5}{8}$ inches wide by $2\frac{9}{16}$ inches thick, while the smallest pipe is composed of 31 staves $5\frac{9}{16}$ inches wide by $2\frac{1}{2}$ inches thick. Douglas fir is used throughout, while the bands are made of steel, 1 inch in diameter, and spaced from 2 to 12 inches apart according to the pressure imposed by the water. When the latter reached the point demanding closer spacing the pipe was decreased in size, because the bands could not be placed less than 2 inches apart; this explains why the diameter of the pipes is successively decreased. With the exception of one span of 820 feet, the whole of the pipe-line is built in a shallow trench, the section in question being laid in the open, owing to a somewhat sharp depression. Here the pipe is supported upon concrete piers.

Another interesting illustration of the wooden pipe-line in its application to hydro-electrics is offered in North British Columbia at the Falls Creek installation of the Granby Consolidated Mining, Smelting and Power Company, which has established a smelter at Anyox. The water is led from the dam through an opening 72 inches in diameter, controlled by a sluice gate, whence extends a wood pipe-line, 72 inches in diameter, for a distance of 5,817 feet, the initial 150 feet being in tunnel. The country traversed by the line is particularly rugged, and a heavy volume of contributory work in the form of trestling had to be erected to carry it across the deep gulches; the minimum radius of the curvature in the line is 400 feet. This pipe-line is under a static head of 298 feet, and at its lower end it is connected with a 72-inch steel pipe-line, which distributes the water to the various units in the power-house.

A Gigantic Wood Pipe-line

But one of the most interesting of the many wooden pipe-lines is that which was constructed to feed the additional units installed in the extension of the large power-house of the Ontario Power Company, now controlled and operated by the Hydro-Electric Power Commission of Ontario, at Niagara Falls. This gigantic installation is interesting because there are three huge conduits conveying the water, representing three distinct methods. The first conduit is of steel-plate buried in concrete, the second is of reinforced concrete, and the third is of wood staves. The two first-named are each 18 feet in diameter by 6,600 feet in length and deliver sufficient water to generate 162,000 horse-power. The third, or wooden, conductor, is $13\frac{1}{2}$ feet in diameter by 6,700 feet in length, and delivers sufficient water to develop from 40,000 to 50,000 horse-power.

The wooden line, completed in 1919, and built of 95 staves, each measuring 6 inches wide by 4 inches thick, is connected with the intake at the gate-house, which is 20 feet in diameter, by means of a reducer 25 feet in length, built of concrete which, as the name implies, reduces the diameter of the passage from 20 to $13\frac{1}{2}$ feet, the diameter of the pipe. For 1,000 feet of its length from the forebay end, the line is encased in concrete, and at the distributor end for a length of 825 feet similar encasing



WATER FREE AND WATER UNDER CONTROL.

Two wood-stave pipe-lines, 10 and 12 feet in diameter respectively, leading the water from the reservoir through the Madison Canyon to the generating station of the Montana Power Company 7,500 feet below. The gulch is so narrow that a special bed had to be blasted and levelled upon the river-bank to receive the two pipes, which are drenched by the spray from the torrent rushing tumultuously alongside.

is followed, but for the remainder of its length it is of straight wooden stave construction.

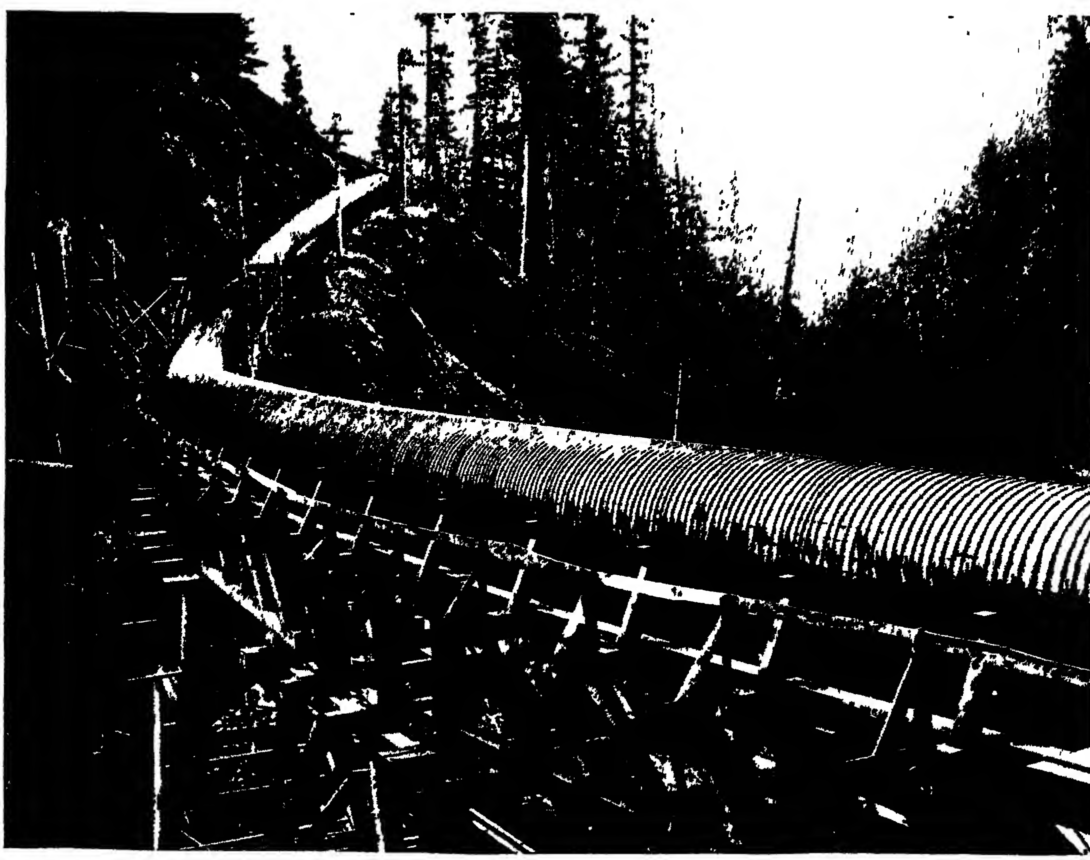
Nevertheless it is the steel pipe-line which brings home to the uninitiated the wonderful strides which have been made in the hydro-electrical world during the past few years. When this form of water conduit grew to a diameter of 4 feet, the spectacle of these water conductors traversing the countryside or descending a hill invariably provoked comments of wonder.

To-day the steel pipe-line is a familiar feature in every country where water-power abounds. One is constrained to reflect and to wonder sometimes as to how the lines can possibly maintain their seemingly perilous position. In passing up the Hardanger Fiord, in Norway, the eye is arrested by two striking works of this character. At Tyssedal an imposing building by the water's edge attracts attention but it is dwarfed by the precipice which sheers up behind. One almost questions how space was found to accommodate the building. Then, as one's eyes become accustomed to the towering cliff, its face is observed to be scarred by four dark lines, almost imperceptible at first, but which, upon closer approach, resolve themselves into pipes. These are the conduits through which the supply, brought from the Ringedals Lake upon the highlands to the brow of the cliff 2,000 feet above sea-level, is carried over the last stage of its journey to the turbines in the building by the water's edge. There are four of these pipe-lines, each 2,395 feet in length, and at one place are laid at such a steep angle as to be nearly vertical. At the top the pipes have a diameter of about 48 inches, but they gradually diminish until at the bottom the

internal diameter is 37 inches. Two of these pipes carry water capable of developing as much power in the five 13,500-horsepower turbines housed below, as is required to drive the *Mauretania* across the Atlantic at 25 knots.

A little lower down this fiord is another hydro-electric station, where the reserve of water, which is tapped at an elevation of 2,880 feet, is only about 1,800 yards from the shore, and the whole of this high head is utilized to drive the turbines, also situated by the water's edge. Here, again, while the diameter of the pipe at the top, or intake, is 48 inches, it is but 33 inches at the lower extremity. The water brought down by this pipe-line strikes the buckets of the Pelton wheel by which the generator is driven, with a pressure of 1,250 lb. per square inch—more than five times the pressure of the steam maintained in the boiler of the locomotive hauling a train at sixty miles an hour. Little wonder that extraordinarily delicate devices are required to keep the water and machinery under control, not only for the protection of the latter, but to prevent damage being inflicted upon the pipe-line as the result of surging, or back-pressure, in the pipe.

The circumstance that water is an excellent servant, when under complete control, for the generation of electricity, but a bad master if it should get out of hand, was brought home very convincingly in this instance. Shortly after being brought into operation the pipe-line burst about half-way up the cliff. A miniature Niagara suddenly came to life, and, owing to the



OVERCOMING THE RUGGED MOUNTAINS OF NORTHERN BRITISH COLUMBIA

How the water is brought down by the 72-inch wooden pipe-line to operate the electrically-driven plant of the Granby Consolidated Mining, Smelting and Power Company at Anyox, showing trestle for the support of the line across a gulch.

head, it quickly spread devastation. It fouled the telephone poles wherewith communication between the intake and the power-station was maintained, picking them up and snapping the wires as if they were pack-thread. In fact, it was a somewhat gigantic monitor which had broken loose, and it visited havoc upon everything with which it came into contact. The interruption of telephonic communication was the most severe blow, because the fact that something untoward had happened was not realized for a few seconds. Then the gates at the intake were promptly shut, cutting off the flow. The frolicsome water only enjoyed a fleeting freedom, but the brief period it was loose sufficed to inflict considerable damage upon the pipe-line and the power-station below.

The Big Creek System

Another installation which is notable for the high head under which it works is that upon Big Creek, which forms part of the extensive system of the Southern Californian Edison Company. In this instance the storage reservoir lies 7,000 feet above sea-level; its creation is due to the rains precipitated and snows melting upon that continuous towering array of snow-capped peaks known as the Kaiser Range of the Sierra Nevada mountains. The water running off the land gravitates in a depression, which, when fully charged, overflows to form Big Creek. The Creek follows a tumultuous course, dropping 4,000 feet in the course of six miles before it empties itself into the San Joaquin River. The lips of this huge saucer lying among the mountains, and over which the water escaped, were raised to increase the storage capacity of the reservoir.

The water thus conserved, instead of being permitted to tumble from crag to crag on its idle way to the sea, was turned into a tunnel 12 feet square and three-quarters of a mile in length. The lower portal of this subway is fitted with a steel **Y** to give access to two pipe-lines, each 9 feet in diameter, only one of which was completed in accordance with the initial development. From this point the water continues to flow through a pipe-line 9 feet in diameter for about a mile; the course taken follows approximately that of the Big Creek itself. Here it discharges into stand-pipes from which extend two 9-feet pipe-lines or penstocks, 2,000 feet in length, laid upon a continuous incline formed by the flank of the mountain to the upper power-house lying 5,000 feet above sea-level.

Pipes of European Manufacture

Just above the power-house Big Creek is swelled by the waters coming from two tributaries — Pitman and Snowslide creeks respectively. These waters were trapped by throwing a dam across the Big Creek course, into which the tail-races from the power-house discharged. The water, deprived of the momentum gained by swinging down the 2,000-feet incline, is diverted into a second tunnel, 4 miles in length, terminating in another stand-pipe and surge tank, whence extend two more penstocks, each 9 feet in diameter, to be conducted over another 2,000-feet abrupt drop. It is turned into a second power-house, and so is made to perform useful duty twice over in the course of its fall. After having actuated the water-wheels in the second station, the water is returned to its natural bed—Big Creek—and allowed to flow on to the San Joaquin River.

Owing to the dimensions and weight of these pipes—they were made in Europe and shipped from Antwerp to San Francisco, making the long sea-passage by way of Cape Horn in a vessel specially chartered for their transportation, and were then hauled to the top of the inclines by railway —their setting in position proved no easy task. Upon the steep inclines a special track was laid, and the pipes were lowered into position from the top; the pipe-

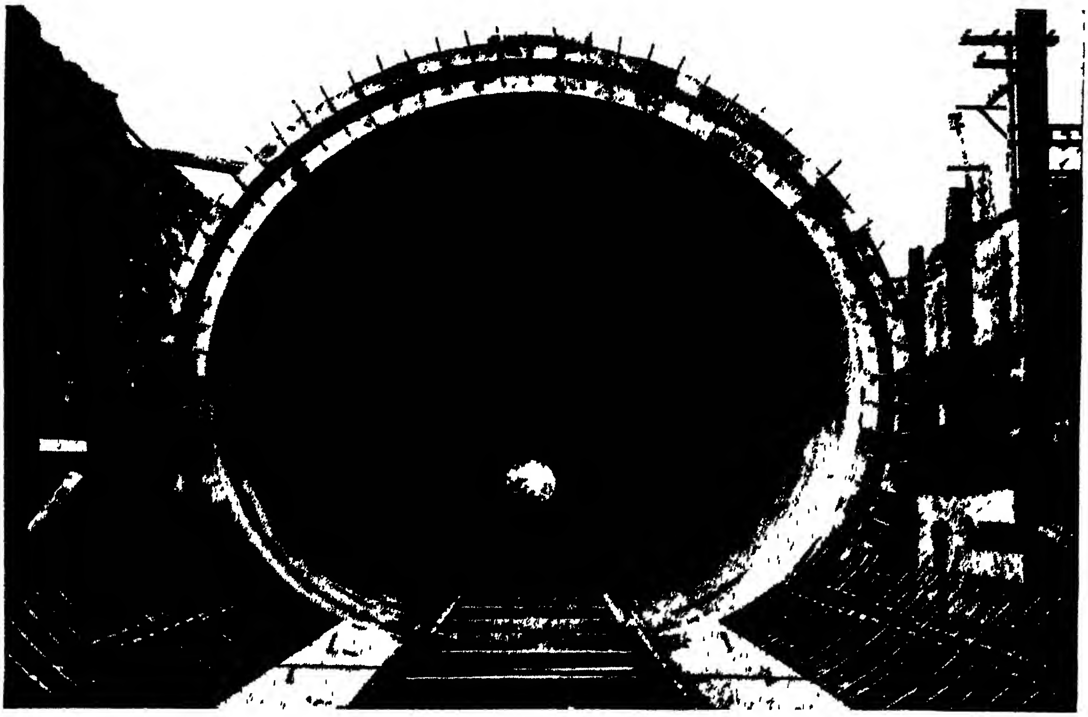
setting machine, somewhat reminiscent of the railway track-layer, crawled step by step, corresponding to a pipe-length, up the steep bank. In order to keep the pipes firmly fixed in position massive anchorages of concrete had to be built on the mountain side—huge monoliths as stout and as durable as the granite upon which they stand. It will be seen that in this instance the total head of water available, namely, 4,000 feet, has been utilized, but in two stages each of 2,000 feet. The water enters the space in which the water-wheels are mounted at the velocity of 350 feet per second—nearly 240 miles an hour. It dashes with great force from the nozzle to impinge upon the buckets of the wheel, but produces no shock whatever. After having performed its designed duty it is brought almost to rest, practically deprived of pressure and velocity during its short passage over the surface of the buckets, and drops inertly from the wheel into the tail-race.

In the Electron installation of the Puget Sound Traction, Light and Power Company's system a high head of water is turned to account, namely 872 feet, and in a single stage. The water brought by the timber flume from the intake upon the Puyallup River and discharged into the settling basin which has been built on the crown of the mountain shoulder, is conducted to the water-wheels below through penstocks 1,700 feet in length. Striking and revolving the wheels, the water is ejected through the tail-race ports in the power-house wall, then strikes the opposite bank of the narrow creek—to dash madly in foam and spray into the air.

The circumstance that the diameter of the steel pipe-line is persistently growing

28,000 TONS OF WATER IN LEASH

The twin steel pipe-lines, 15½ feet in diameter, 2,350 feet in length, for which over 2,400 tons of steel were used, to carry the hydraulic energy drawn from the Missouri River for the operation of the Rainbow Falls hydro-electric plant of the Montana Power Company.



NOT A RAILWAY TUNNEL, BUT THE REINFORCED CONCRETE CONDUIT OF THE HYDRO-ELECTRIC COMMISSION AT NIAGARA FALLS.

It is 18 feet in diameter, 6,500 feet in length, and carries sufficient water to drive turbines of 80,000 horse-power. This hydraulic "tube" is noteworthy for its novel distorted shape.

to meet the demand for more and more powerful generating units, is brought home very strikingly in the case of the conduits laid down by the Montana Power Company in connexion with its harnessing of the Rainbow Falls upon the Missouri River. The water impounded by the dam is led through two pipes, built up of riveted steel, 15 feet 6 inches in diameter. The mere iteration of the measurement fails to convey a conscious impression of their size. A man standing on the shoulders of another could scarcely touch the roof. The tunnels of the London "Tuppeny Tube" could be placed inside them and leave plenty of room to spare. A Pullman car could be passed through the line from end to end with ease. These two lines laid side by side are 2,350 feet in length, and the total weight of steel worked into them weighed 2,471 tons, while 436,000 rivets were required to secure the sections of plate together. Arrangements are introduced to allow either tube to be shut down and emptied to permit inspection, overhaul, or painting, as required, the other line remaining in service meanwhile.

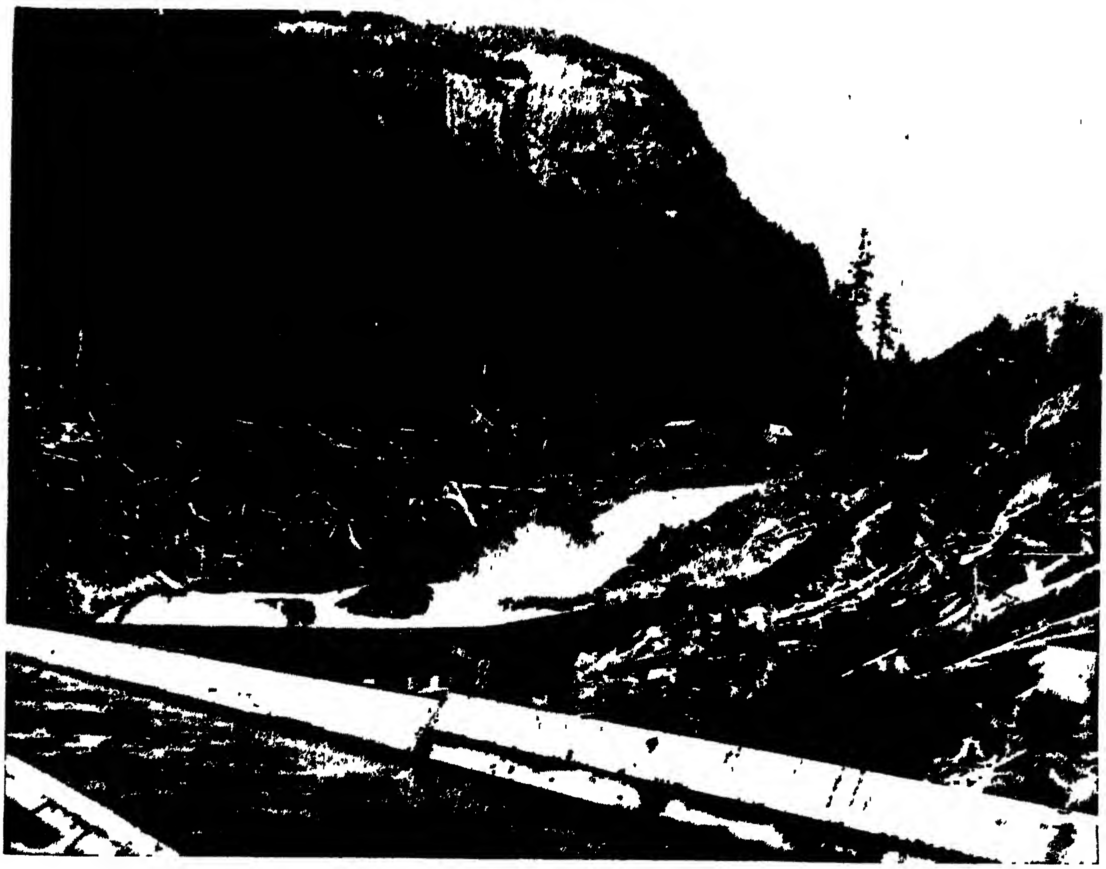
When these two pipes are fully charged the total weight of the water within is 28,000 tons. Control of such a massive volume needs to be effected with extreme care, although in this instance there is an absence of that velocity incidental to a position where the water is permitted to tumble down a mountain side though encased in a steel cylinder. Nevertheless, such an enormous weight is not easily started, and when once in motion cannot be readily stopped.

To such huge proportions have some of these water conductors been advanced as to render the word "pipe-line" almost a misnomer; tube would be more appropriate, especially as we apply the term to the underground railways which are laid in large-diameter steel-pipes. And as the

diameter of the conduits increases, so do expressions of ingenuity upon the part of the engineer become more manifest.

During the past few years many interesting departures from what might be called orthodox practice have been made. The most important among these, owing to its magnitude, was that of the Hydro-Electric Power Commission of Ontario at Niagara Falls, in connexion with the second conduit, to which reference has already been made. The tube is not circular, but is given the shape which one of such diameter, if elastic, would assume if filled with water and were under a similar hydraulic head. While it has an equivalent diameter of 18 feet, it measures 19¼ feet horizontally by 16½ feet vertically. A railway train could be run through this pipe-line without difficulty. It is made of reinforced concrete, and in its construction the bottom part was formed first, the upper section being carried out by means of collapsible movable forms carried on trucks. When finished the surface was smoothed to reduce losses from friction. This tube is 6,500 feet in length, and when the water within is moving at the designed maximum velocity it represents 90,000 horse-power. This tube delivers sufficient water, therefore, to operate the battery of turbines having an aggregate output of 80,000 horse-power, and is probably the largest water conductor that, so far, has been built for the generation of electricity by hydraulic energy.

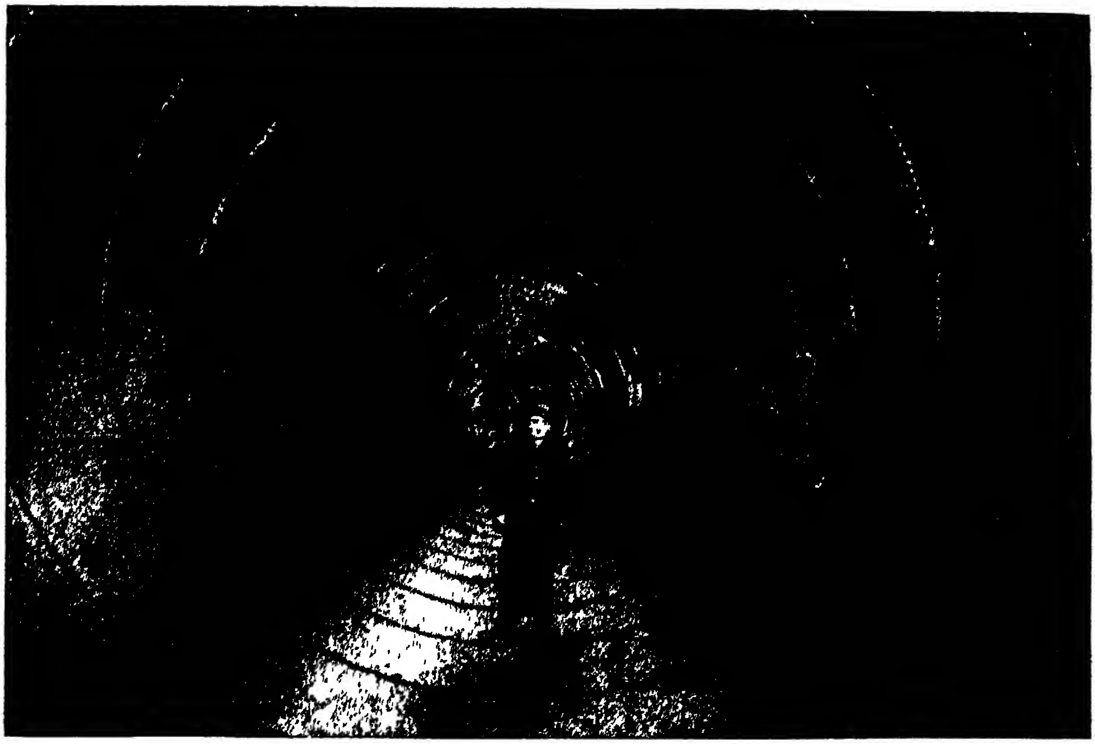
A necessary adjunct to the pipe-line is the relief valve whereby surplus water,



HOW THE STEEL PIPE-LINE FOLLOWS THE NATURAL CONTOUR OF THE GROUND
The water conduit, 12 feet in diameter, of the Ocean Falls Company, British Columbia, and Link River, near the power-house.

arising from the high pressure set up when the gates controlling admission to the turbines are closed and the backward pressure which results, may be discharged. In some instances what is known as a bursting plate is inserted in the penstock. As the pressure set up might attain such a point as to disrupt the whole fabric, thus closing it down for an indefinite period, the bursting plate, which is the weakest part of the structure, acts as a safety-valve, and its collapse ensures an escape for the water. But this, while indisputably effective, cannot be entertained by a large combination with a heavy supply commitment, because the penstock must be shut down to allow the burst plate to be replaced.

Accordingly, ingenuity has been centred upon the evolution of a simple relief valve system, such as has been introduced into the plant of the Shawinigan Water and Power Company, of Quebec. In this instance the 20,000-horse-power turbines are fed with water travelling at a speed of 8·5 feet per second under a 145-foot head, through penstocks 600 feet in length by 14 feet in diameter. Each penstock is bifurcated, so that each branch leads to the wheel-case of a turbine, and the relief valve is so disposed that the water, in the event of abnormal back-pressure being set up, is discharged from the feeder pipe into the draught tube, and thus escapes into the tail-race without passing through the turbine wheel-casing. This valve is automatic in its action, and in operation has proved wonderfully efficient.



INSIDE ONE OF THE TWIN STEEL PIPE-LINES OF THE RAINBOW FALLS POWER DEVELOPMENT.
The "tunnel" has a diameter about 50 per cent. greater than that of the London Tube railways. A railway train could pass through with ease.

The surge tank is another device for assuring the regulation of the flow of the water through penstock and flume. One of the most notable installations of this character is that at Niagara Falls (see p. 213), into which the water conducted by the huge reinforced concrete tube, already described,

is discharged. The surge tank comprises what might be called an outer vessel enclosing a stand-pipe, or riser, the top of which is open, while disposed round the wall just below the open mouth are a series of ports. This riser is connected to the conduit. When a surge sets up it causes the water to rise in the stand-pipe until it overflows through the open ports. If the "kick" is sufficiently pronounced the water will pour not only through the ports, but the open mouth of the riser as well. The water thus overflowing from the stand-pipe falls into the body of the outer vessel which forms the storage tank; from the ports in the bottom of the latter the conduit is able to draw its supplies. All surplus and overflow water in the tank is discharged into the river through a tunnel, the mouth of which is level with the ports of the riser and 4 feet below the head-water level at the intake forebay.

In the case of the Coquitlam-Buntzen development the tunnel conducting the water from Lake Buntzen to the second power-house is fitted with a surge tank near the delivery portal. This tank is constructed of steel plates riveted together, and is 90 feet in height by 30 feet in diameter, placed in a shaft excavated in the rock. The tunnel discharges its water into this tank. The three penstocks, serving the turbines placed in the power-house below, are connected to this tank, and the ends of the pipe-line are carried through openings in the wall of the structure, and secured thereto with flanged reinforcing plates, to form a water-tight joint; the penstocks at this junction are $3\frac{1}{2}$ feet in diameter. Thus the penstocks collect the water they require from the tank, which also absorbs all the surges that may arise from the variation in the load. The surge tank is one of the more recent developments in hydro-electric

Photo Montana Power Company

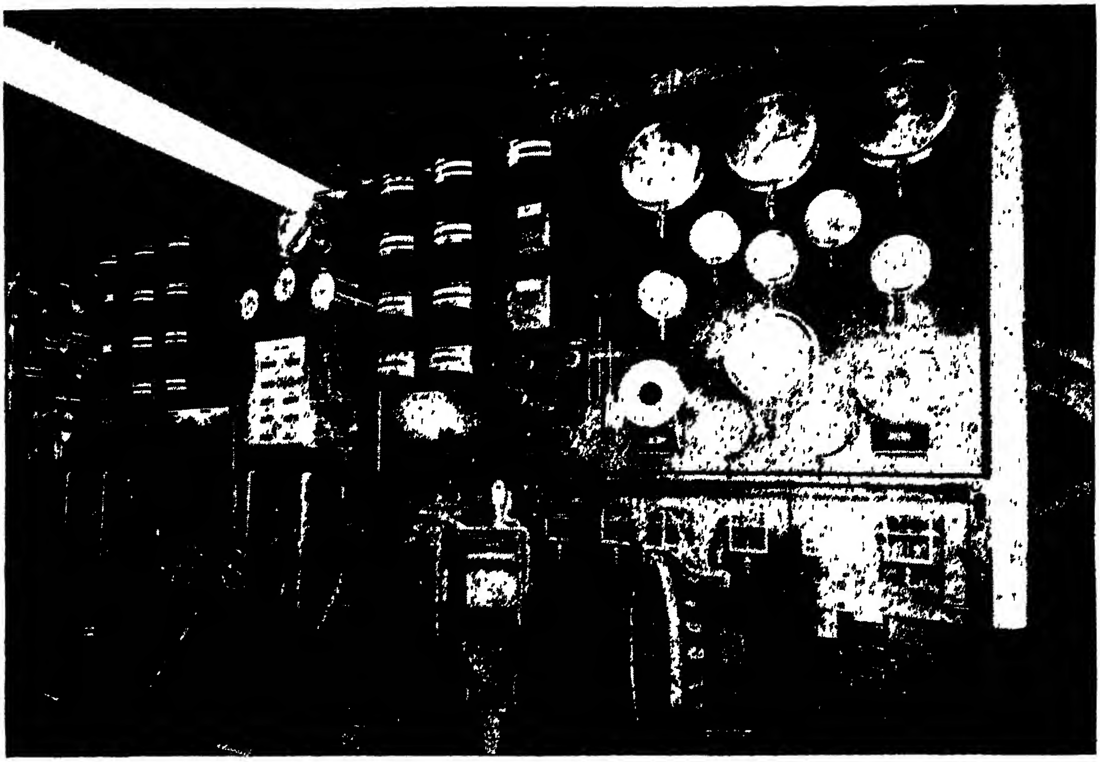
WHAT THE INTERIOR OF A SCROLL-CASING IS LIKE.

The huge specially shaped steel tube which leads the water to the turbine.

practice, especially where long and large pipe-lines are concerned, and is coming into increasing favour for the efficient regulation of the water-supply to the water-wheels.

Surveyed from a suitable coign of vantage along its route the pipe-line, extending over the ground, following its configuration and resembling a gigantic serpent, appears to be a simple means of carrying the water from the point where it has been brought under control, to the power-house where it is to be compelled to perform useful service. It may occasion a thought of admiration because of the dimensions to which the engineer has been induced to advance, while the daring associated with its construction may excite comment. But it is merely regarded as a carrier; its form reveals nothing of the intricacies incidental to its employment, nor does it convey a proportionate idea of the enormous amount of energy stored up in the moving contents, and which is designed to be dissipated in rotating the turbine to which the generator is coupled for the supply of cheap electric power in bulk.

THE SURGE TANK—THE SAFETY-VALVE TO THE PIPE-LINE.
The surge tank shown in this illustration, for the No. 2 Coquitlam-Buntzen hydro-electrical development, sunk in the solid rock, and built of steel, is 90 feet in height by 30 feet in diameter. The penstocks are connected to the tank at the openings shown.



THE BRAIN OF THE ELECTRIC BATTLE-SHIP.

Section of main control-board, United States battle-ship, *New Mexico*, showing levers for changing speed and reversing course of ship, also operating instruments and gauges.

The Electric Battle-ship

THE MAKING OF A FLOATING POWER-STATION WHICH ENERGIZES EVERYTHING FROM A TOASTER TO A BROADSIDE

FOR many years past the adoption of electricity for the propulsion of ships has been energetically urged by engineers on both sides of the Atlantic. Conspicuous among these advocates are Mr. W. S. Durtnall in Great Britain, and Mr. W. L. R. Emmet in America. Each has vigorously championed the cause in his own country, and although these proposals were fully discussed, no apparent inclination was shown to submit them to practical test. In view of the triumphs achieved by electricity in the world of traction ashore, one might urge that the mercantile marine has been excessively cautious. It has installed electricity for the performance of a thousand and one subsidiary duties on board; the engine-room of every modern liner carries an impressive generating station. Of course, the application of electric traction to a railway is vastly dissimilar from the utilization of the same force in an identical manner upon the sea. In the one instance the unit is able to draw its energy from a conveniently disposed conductor, which in turn can derive

its power from one or more of a dozen generating stations. But upon the high seas the mobile unit must be completely self-contained, and must develop the power it requires upon the spot.

Nevertheless persistent pleading of the cause induced the American Government to take the plunge. As a trial effort, the vessel *Jupiter* was equipped with electric motors, and her behaviour under all conditions closely studied. The misgivings which had been entertained concerning the suitability of electricity for such duty were completely dispelled. Accordingly, when it was decided to embark upon the construction of the new class of battle-ships, of which the *New Mexico* was the first, electric propulsion was unhesitatingly adopted, and Mr. W. L. R. Emmet, consulting engineer to the International General Electric Company, of Schenectady, which was entrusted with the construction of the equipment, was given the opportunity to vindicate his theories.

The Trial Ship

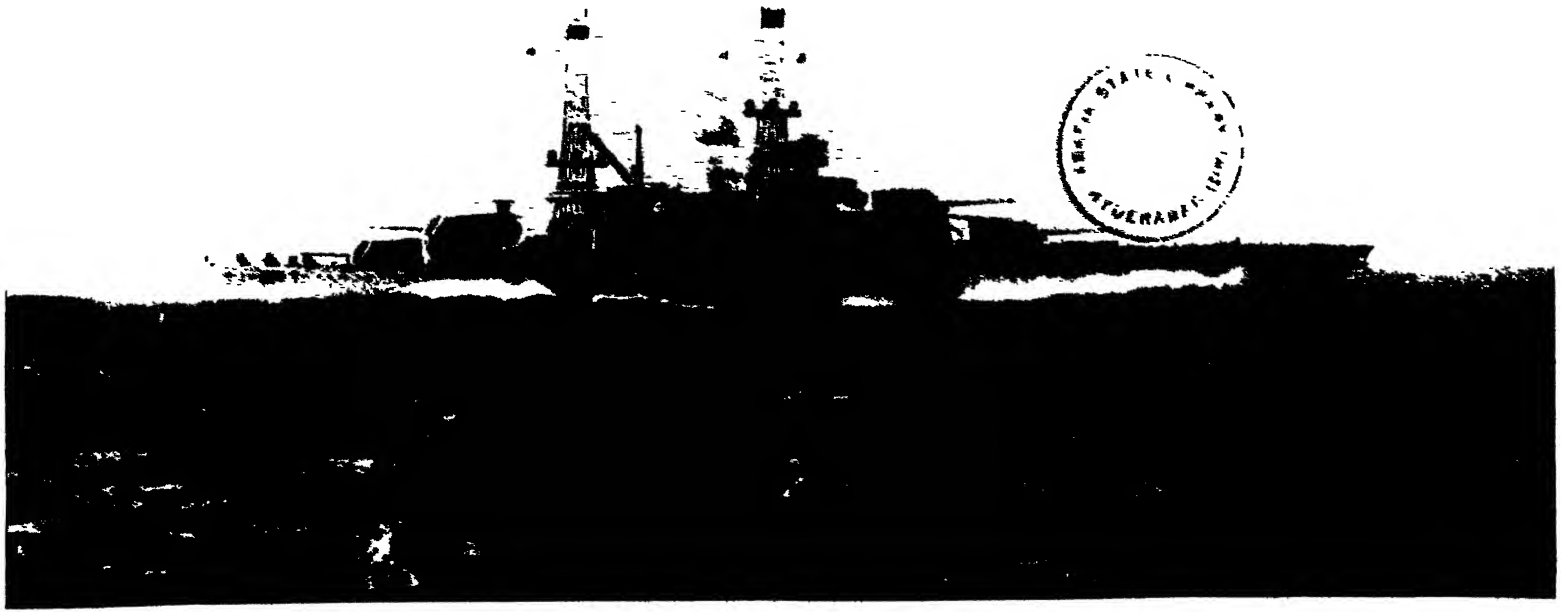
The *New Mexico* measures 620 feet overall, is of 96-feet beam, displaces 32,000 tons, and has a speed of 21 knots. This speed is attained by the installation of electric motors developing 28,000 horse-power. Steam is raised by nine oil-fired boilers, and the ship has sufficient tankage capacity to carry 3,400 tons—approximately 1,000,000 gallons—of liquid fuel, which is fed to the furnaces of the boilers through nozzles at a pressure of about 300 lb. per square inch. The steam thus raised to a pressure of 280 lb. is passed to turbines to which the electric generators are directly coupled. There are two of these units, each developing 17,000 horse-power, and each capable of driving the vessel at three-quarters speed. They are housed in separate compartments, 53 feet in length by 17 feet in width, set low down in the ship.

There are certain distinct advantages accruing from the employment of electricity for propulsion. The engine-room of the conventional vessel is arresting because of its maze of big pipes, but in this American battle-ship there are only two steam-pipes, one to each turbo-generator, and they are but 16 feet in length. The engine-room is further simplified because there is no reversing turbine or mechanical gears; reversing is done electrically. The turbines to which the generators are coupled always run in the one direction, and this not only contributes to simplicity but to high efficiency.

From the engine-room, or each unit of the power-plant, eight electric cables are carried to the switches of the control-board; thence the current is led to the motors which drive the propellers. The battle-ship is driven by four screws, each mounted upon its own shaft, and driven by its own motor. Each of these motors is about 12 feet in height, develops 7,000 horse-power, and is mounted in its own steel compartment. By this system of individual electric drive another advantage is gained. The propeller-shafts can be made shorter than is normally possible, because the motors can be placed close to their respective propellers. It will be seen that the propulsion of the ship becomes divided into two distinct sections—the turbo-generator and the motor with propeller respectively. Their disposition in relation to one another is immaterial. The turbo-generators can be placed immediately contiguous to the boilers, even at one end of the ship, and the motors and their propellers at the other end. The only connexion between the two, via the control board, is by copper cables which can be run in any direction. It is far easier to stow a few cables in a small duct, out of the way, than to carry steam-pipes from point to point.

The Electric Drive

The control-board is the brain of the ship. The cables radiate from this point like nerves, capable of being excited



THE ELECTRICALLY-DRIVEN AMERICAN BATTLE-SHIP, *NEW MEXICO*, TRAVELLING AT 21 KNOTS.

This warship, measuring 620 feet overall and displacing 32,000 tons, is driven by two turbo-generators, each developing 17,000 horse-power, furnishing current to four 7,000-horse-power motors, each coupled to its own propeller. This vessel is electrically operated throughout; the motors installed on board for any and every duty aggregate nearly 100,000 horse-power.

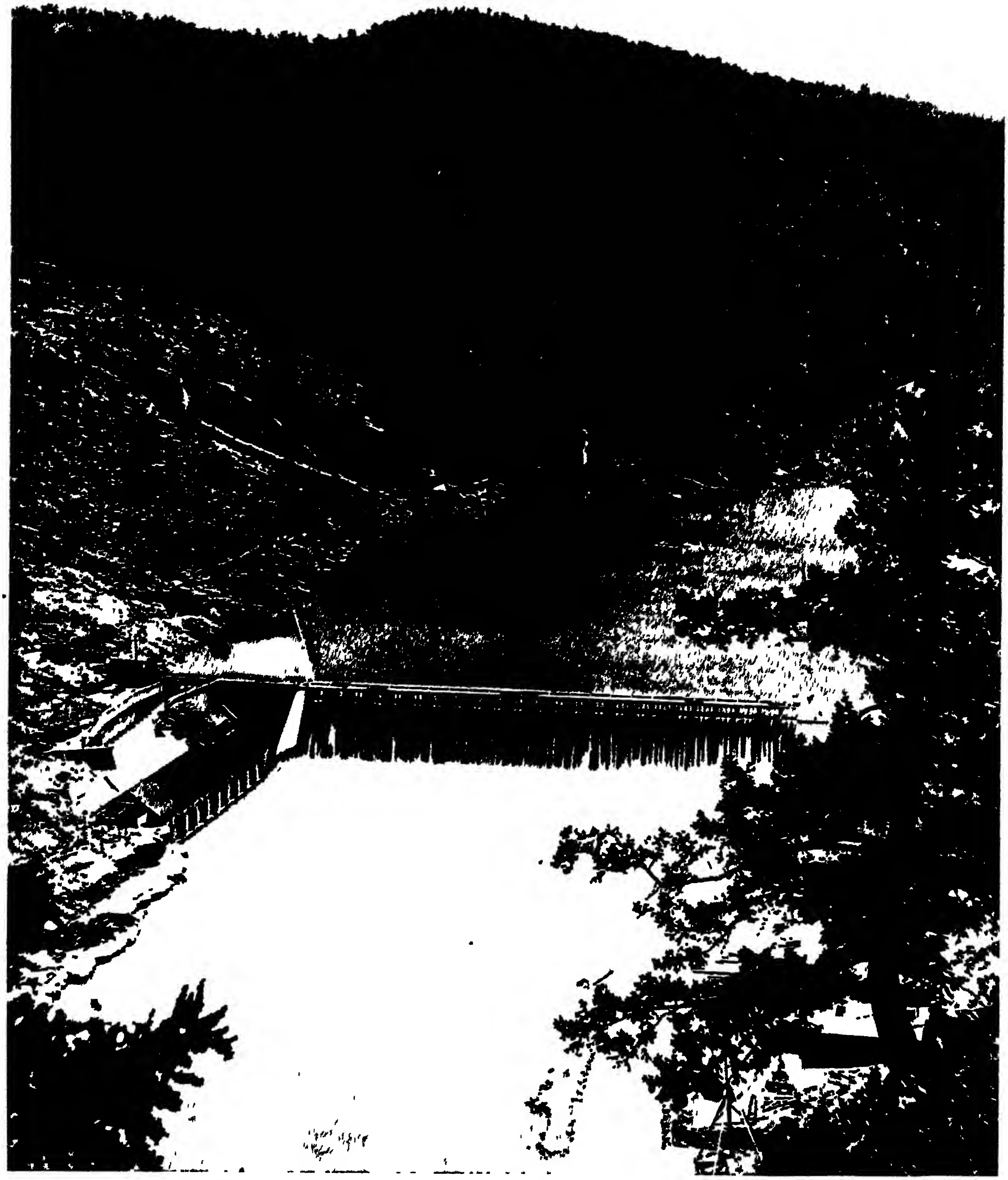
according to requirements. The engineer can run all propeller motors off one turbo-generator, or he can divide the work equally between the two. He can vary the speed just as the navigating officer desires, and can start the vessel backwards or forwards; the first-named objective is accomplished merely by reversing the motors. He can divide the load by allowing one generator to feed power for driving two motors forward, while, at the same time, the current coming from the second generating unit can be used to run the other two motors and their propellers in the opposite direction. This simultaneous combination of ahead and astern drive is sometimes adopted when it is desired to turn the ship quickly in a narrow channel. Flexibility is one of the outstanding characteristics of electric propulsion.

ONE OF THE 17,000-HORSE-POWER GENERATORS FOR THE AMERICAN BATTLE-SHIP *MARYLAND* IN THE MAKING.

Assembling the stator or stationary part of the generator. Comparison with the mechanics conveys a graphic idea of the dimensions of the unit.

It must also be remembered that, as the turbines and the propellers are quite distinct, without any mechanical interconnexion whatever, it is possible to run both elements at their most efficient speeds. The turbine when run at full speed gives the most satisfactory result in regard to fuel consumption — it is a high-speed engine. On the other hand the propellers demand relatively low speed to give the most efficient return. If they be driven too fast they merely churn the water, and much of their effort is lost instead of being used to force the ship ahead. Under electric operation these two—diametrically opposite conditions — can be completely fulfilled.

This American battle-ship has been described as the "one hundred per cent. electric ship"—the term is equally applicable to the others of the class—because, not only is it propelled in this manner, but every auxiliary on board is dependent upon the same force. Electric operation of the auxiliaries does not represent a new departure; but it is doubtful whether any

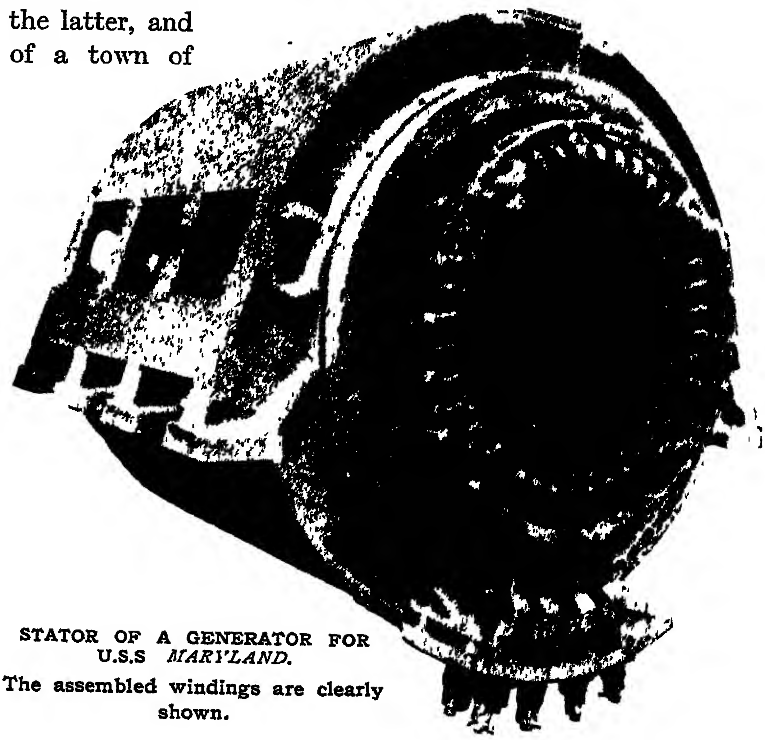


CONSERVING HYDRAULIC ENERGY FOR ELECTRIC POWER.

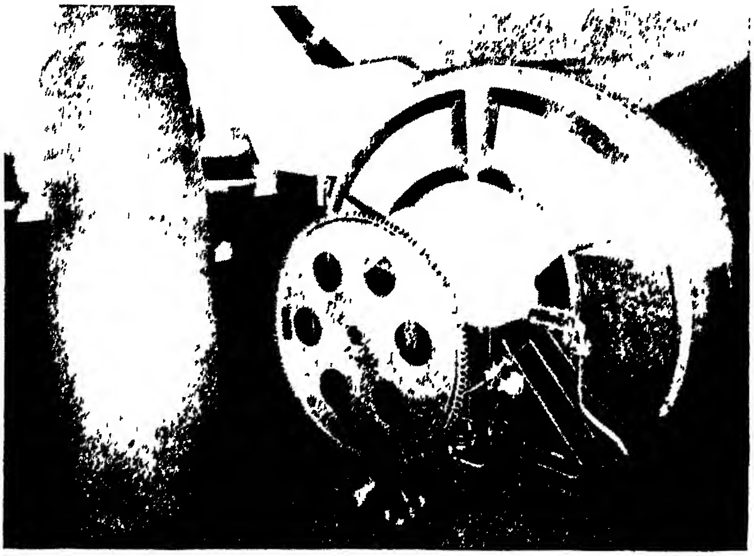
The Hauser Lake Dam on the Missouri River, forming a storage reservoir of 46,000 acre-feet. At the left is the power-house, drawing water from forebay above the dam to produce 18,000 kilowatts.

warship afloat is so completely electrified. The whole of the power required is derived from the two units of the power-station, having an aggregate output of 34,000 electrical horse-power, and these are able to furnish as much current as would be required to light the homes and factories, as well as to furnish energy for the motors coupled to the machines in the latter, and to operate the tramways of a town of 100,000 people. To recite all the duties performed by energy forthcoming from this floating central station would be wearisome, but it may be related that it hoists the ammunition, rotates the gun-turrets, operates the 14-inch guns, and steers the vessel. By this means the anchors and boats are raised and lowered; it is also responsible for the maintenance of the water-supply and sewage-disposal systems; it compresses and heats air; drives the tools in the machine-shop and the printing-shop; furnishes current for the interior communication systems, the elaborate fire-protection and fighting-equipment, the telephones, searchlights, wireless telegraphy and telephony, as well as lighting the floating town from stem to stern and from taffrail to keel.

The aggregate rating of all the electrical machinery stowed aboard is nearly 100,000 horse-power. In addition to the four propeller motors totalling 28,000 horse-power there are 6 dynamos of 2,400 horse-power; 6 air-compressors requiring 300 horse-power; two steering motors of 250 horse-power; 20 motor-generating sets totalling about 100 horse-power; 4 motors of 200 horse-power for hoisting and lowering the boats; two 350-horse-power motors for raising the anchors; four winch motors totalling 200 horse-power; one 50-horse-power capstan motor; 20 turret motors of 500 horse-power; 10 ammunition hoists of 50 horse-power; and two 20-horse-power refrigerator motors. For service in the kitchen 15 horse-power is divided among 8 motors; the tools in the carpenter's shop are driven by 6 motors absorbing 20 horse-power; the machine-shop carries 15 motors totalling 30 horse-power; the printing-shop depends upon 6 horse-power supplied by 5 motors; while the laundry absorbs 10 horse-power with 6 motors—five of the laundry machines using electric heat. The water-circulating system requires 14 motor-driven pumps of 140 horse-power, while 8 horse-power serves 4 motors for the oil-pumping installation. There are 20 electric heaters taking 150 horse-power, and 12 searchlights demanding 200 horse-power. In addition current is needed for 160 fans, 60 blowers, 6 electric toasters, 1 coffee percolator, 15 electric irons, 7 portable electric drills, 2 electric glue-pots, and 6



STATOR OF A GENERATOR FOR U.S.S *MARYLAND.*
The assembled windings are clearly shown.



ONE-HALF OF THE ELECTRICAL POWER BEHIND THE *NEW MEXICO*.
Each of the main generators develops more than 15,000 horse-power of electric current.

loss of an anchor. The boat-cranes are called upon to carry the heaviest loads, such as the ship's steam cutters, carried on the deck of the vessel, each of which weighs 40,000 lb. These cranes also have a fairly high hoisting speed to assure supplies being taken aboard in the least possible time. They lift the material to the deck, but the distribution of the supplies is effected by means of the motor-driven deck-winches, which are more convenient for moving loads through the hatches.

electric soldering irons. The intercommunicating service is equally complete; there are 104 loud-speaking, 176 ship-service, and 170 fire-control telephones. The loud-speaking telephones are distributed throughout the ship. There are three transmitting stations from which bugle calls or instructions can be sent to any one, or all, of five different groups of telephones. Last, but by no means least, come the two compasses which are of the Sperry gyroscope type depending upon the electric motor.

Among the auxiliary applications of electricity for the working of the ship may be mentioned the steering gear, the control of which thereby proved to be no easy problem. The main motors are in duplicate, and there are five different control stations. The rudder can be moved by six different means, including compressed air and electric current furnished by a storage battery. Then there is the device for raising the three anchors, each of which turns the scale at 20,000 lb. The electrical raising control is so designed as to imitate the action of a fisherman hauling in his line, for the purpose of avoiding such strain upon the chain as might precipitate the

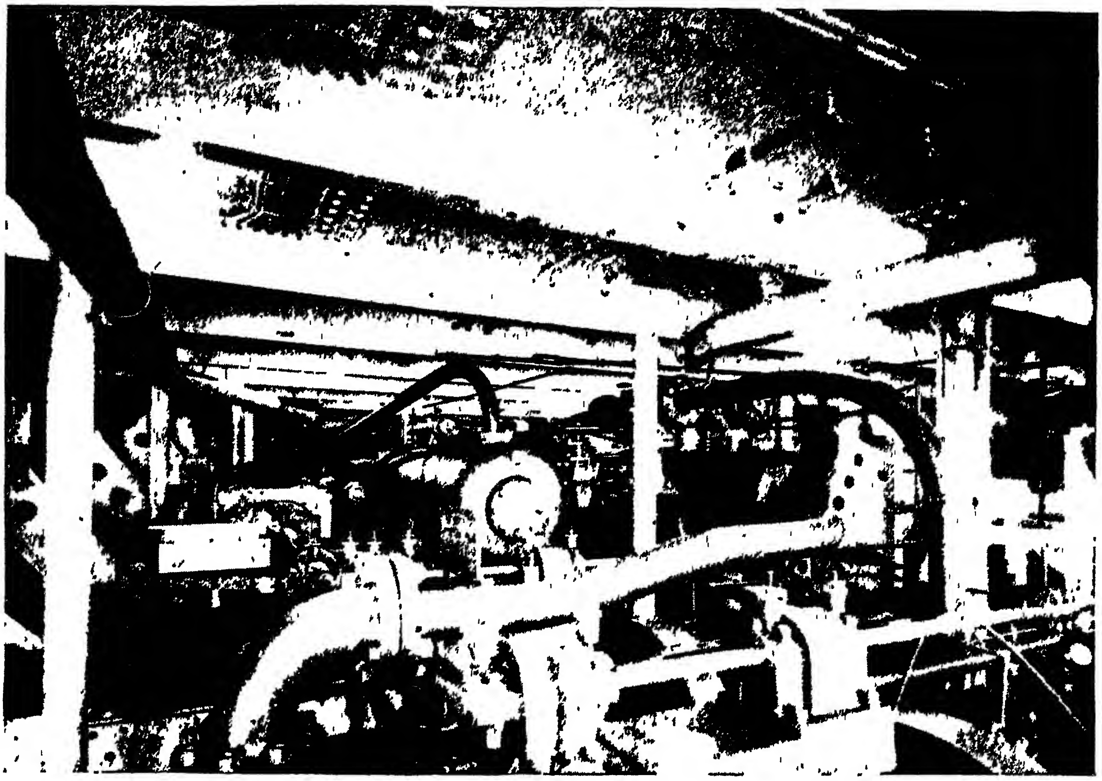
The rotation of the turrets, as well as the elevation and loading of the 14-inch guns are primarily dependent upon electric energy. In rotating the turrets it is imperative that the motion should be constant irrespective of the speed. To assure this end, a combined electro-hydraulic system is adopted. The motors maintain a constant speed, while the variations in the revolving speed of the turret are accomplished by means of hydraulic gears. Finally the guns are fired by the aid of electric primers. Electric motors charge the flasks of the torpedoes with compressed air, which forms the motive power for the delicate motors propelling the missile after entering the water, to a pressure of 3,000 lb. per square inch. It may also be mentioned that the magazines are maintained at a regular cool temperature by means of a refrigerating plant which is likewise electrically driven; while testing ovens heated by electricity are employed for the preservation of samples of the explosives at a constant temperature. These samples are examined daily, and when brown vapours are observed to be forming they prove that the explosives concerned are deteriorating through age.

The foregoing pertains to what might be described as the business or militant aspect of the battle-ship. There is the household side to be taken into consideration, and it is one of decided importance, seeing that the *New Mexico* is the floating home of some 1,100 men. The uses of electricity in domestic service aboard are just as striking and impressive. There is no "spud drill" upon this warship, because the potatoes are peeled by electricity much more economically and efficiently than is possible by hand, and with a marked saving of time. The American sailor does not consider life to be worth living without a daily contribution of ice-cream, but manually turning the crank of the freezer is irksome and deprives the delicacy of much of its attraction; meat-mincing is another phase of drudgery. In both instances on this ship small electric motors take the place of brawn and muscle. The equipment of the kitchen includes an electric dish-washer and butter-cutter; while knives are polished and sharpened by electrically-driven machines. Bread is an electric product; the baking is done in electrically-heated ovens. The laundry is likewise electric. The electric iron is also a decided acquisition to the tailor's shop. Electric toasters and a coffee percolator are upon the table, while satisfactory ventilation is maintained in the mess by electric fans. The hospital is equipped throughout with the most modern electric devices, including a sterilizer, and special systems of illumination and ventilation.

In contracting for the supply of the propelling equipment the International General Electric Company had to face somewhat onerous terms. The total weight of the apparatus, complete with the required spare parts, was not to exceed 700 tons. For every ton over and above this figure a penalty of £100 was to be exacted, plus an additional £2,000 if the complete weight came out at 735 tons or more. As a matter of fact, the total weight of the apparatus furnished according to specification came out at 590 tons.

Severe penalties were attached to the guarantees concerning steam consumption. These were based upon a steam-gauge pressure at the throttle of 250 lb., and dry saturated steam, with the following corrections: if superheat were used, then the guaranteed steam consumption was to be

THE DRIVE OF THE ELECTRIC BATTLE-SHIP.
One of the four 7,000-horse-power motors, 12 feet in height, showing direct connexion to the propeller shaft.



THE ELECTRO-HYDRAULIC MACHINERY FOR MOVING THE RUDDER.
It requires as much power to control the rudder of the electric battle-ship as it does to drive an ordinary tram-car.

reduced at the rate of 1 per cent. for each 13 degrees Fahrenheit of superheat observed at the turbine; if the steam contained moisture, then the guaranteed steam consumption was to be increased at the rate of 2¼ per cent. for each per cent. of moisture present in the steam at the turbine. The guarantees covered the total amount of steam used both by the main generating units and specified auxiliaries. On the basis of a pressure of 250 lb. at the throttle and dry steam, the consumption was not to exceed 15·38 lb. at 10 knots; 11·57 lb. at 15 knots; 11·32 lb. at 19 knots; and 11·53 lb. at 21 knots per shaft per horse-power-hour. If the guarantees were not fulfilled, then a penalty of £5,000 per lb. for 10 and 15 knots, and £4,000 per lb. for 19 and 21 knots deficiencies were to be paid. The contract price for the whole of the equipment was set down at £86,200.

The method of operation is interesting. Each of the two main turbines is connected to a quarter-phase generator having two poles. The four propelling motors are so wound that by suitable changes of connexions, made through groups of oil-switches on the control-board, the windings can be set either for 24 or 36 poles. The ratio of speed reduction between the turbine and propeller is approximately 12 : 1 to 18 : 1. For speeds up to about 15 knots, as well as reversing, the 36-pole connexion is used, giving way to the 24-pole connexion from 15 knots to the maximum speed. Each turbine is furnished with a special type of governor whereby, through the movement of a fulcrum connected thereto by a device at the operating board, the speed can be held at any desired point within the range. When running steadily up to about 15 knots, only one turbo-generator with its auxiliaries is used; all the motors

are then connected for 36 poles, and the speed ratio reads 18 : 1. If speed is required up to 17 knots from the one generating unit, the pole connexions are changed to 24, giving a speed ratio of 12 : 1. For speeds between 17 and 21 knots both generating units are brought into operation; each operates a pair of motors, and the two circuits are separate from one another. When both generating units are in service the windings of each generator are connected in series to give the required higher voltage for maximum speed; but at 17 knots, with one generator in duty, the windings are connected in multiple by means of a switch to reduce the voltage and increase the current capacity of the generator. When both generators are used for steady running the motors are always connected up for 24 poles for economical reasons. The ship can be started with either one or both generating units, and with the motors connected for 36 or 24 poles.

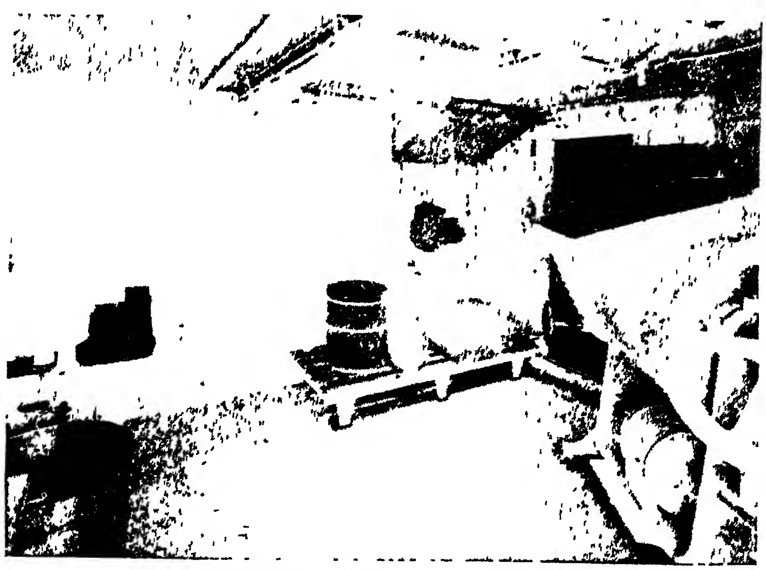
The ventilation of the generators demanded careful study. When running all out, making approximately 2,000 revolutions per minute, each generator requires 38,000 cubic feet of air per minute for its efficient ventilation. A fan capable of delivering this quantity of air is mounted at each end of the rotor; but in view of the resistance of the air-ducts between the generator and the deck, these fans were supplemented by independent blowers. Two fans were fitted to each generator; each is capable of delivering 20,000 cubic feet of air per minute. They are placed in a room directly over the generators, and the air drawn from the deck above is driven through ducts into large enclosed compartments beneath the generators. This air, after doing its work, is carried up to the

THE ELECTRIC LAUNDRY OF THE ELECTRIC BATTLE-SHIP.
Clothes and linen are washed, dried and ironed by the aid of current. Five of the machines use electricity for heating as well as power.

deck for discharge. Each motor also demands 20,000 cubic feet of air a minute when working under the most severe conditions; to assure adequate cooling each is similarly furnished with two independent blowers, in addition to the blower-action of the rotating element. Each independent blower passes 10,000 cubic feet of air a minute through the motor.

As may be supposed, the trial trips were of a searching character. In the high-speed trial the *New Mexico* developed and maintained a speed of 21¼ knots continuously for four hours, although running at a displacement 1,000 tons in excess of the design. One of the greatest advantages claimed for the electric drive is interchangeability, and twice, during the preliminary runs, this virtue was revealed. While running at 17 knots, with both generators in service, a small pipe in the circulating pump system broke. The pump had to be shut down to allow a new pipe to be fitted, necessitating the cutting out of the generator affected. In less than 10 seconds all the propelling motors were being driven without any diminution in speed, with current supplied by one generating unit. In the second instance, while the ship was making her run on one generating unit the circulation pump became air-bound and lost its suction. In a few minutes the other turbo-generator was brought into service, and the change-over made without the ship's speed being affected. The gun-fire tests were regarded with the greatest apprehension, because there was much speculation about what would happen to the insulators, cable supports, and delicate instruments under a full broadside. After the twelve 14-inch guns had been fired simultaneously, the whole of the installation was minutely inspected, but no sign of failure of any part was found.

Although the adoption of electric propulsion in ships may be said to be an innovation, it does not display a new source of power. In a way it represents a complication of the issue, because it involves the introduction of additional power equipment. Electricity does not displace coal or oil, but it permits a given quantity of either of these familiar fuels to do more work with higher efficiency.



THE BAKERY OF THE AMERICAN WARSHIP *NEW MEXICO*.

Bread, biscuits, cakes and pastry, from mixing to baking, are electric products. To run the kitchen of this electric battle-ship there are eight motors furnishing 15 horse-power.

THE FIRST ELECTRICAL SUBJUGATION OF THE MISSOURI RIVER.

The harnessing of the Black Eagle Falls, one of five big cataracts, was completed in 1890. Part of the hydraulic energy was used to generate current for the copper-ore reduction works on the right bank, and on the left bank a small station was established to supply electricity to the city of Great Falls.

Taming the Falls of the Missouri River—I

HOW A GREAT AMERICAN HYDRO-ELECTRIC ENTERPRISE WAS CONSOLIDATED

IN the opening days of the nineteenth century, when the North American continent from the Mississippi River to the Cascade Mountains was as little known as the erstwhile province of Ungava, now Northern Quebec, two intrepid spirits set out upon a voyage of discovery. They were bound west, determined at all hazards to gain the Pacific seaboard overland. The names of these two adventurers, Lewis and Clark, are as profoundly honoured in the United States to-day as the name of Livingstone is in Great Britain in connexion with the lifting of the veil from the interior of Africa. The journal which they compiled in such detail, and so graphically illustrated, is the epic of American exploration.

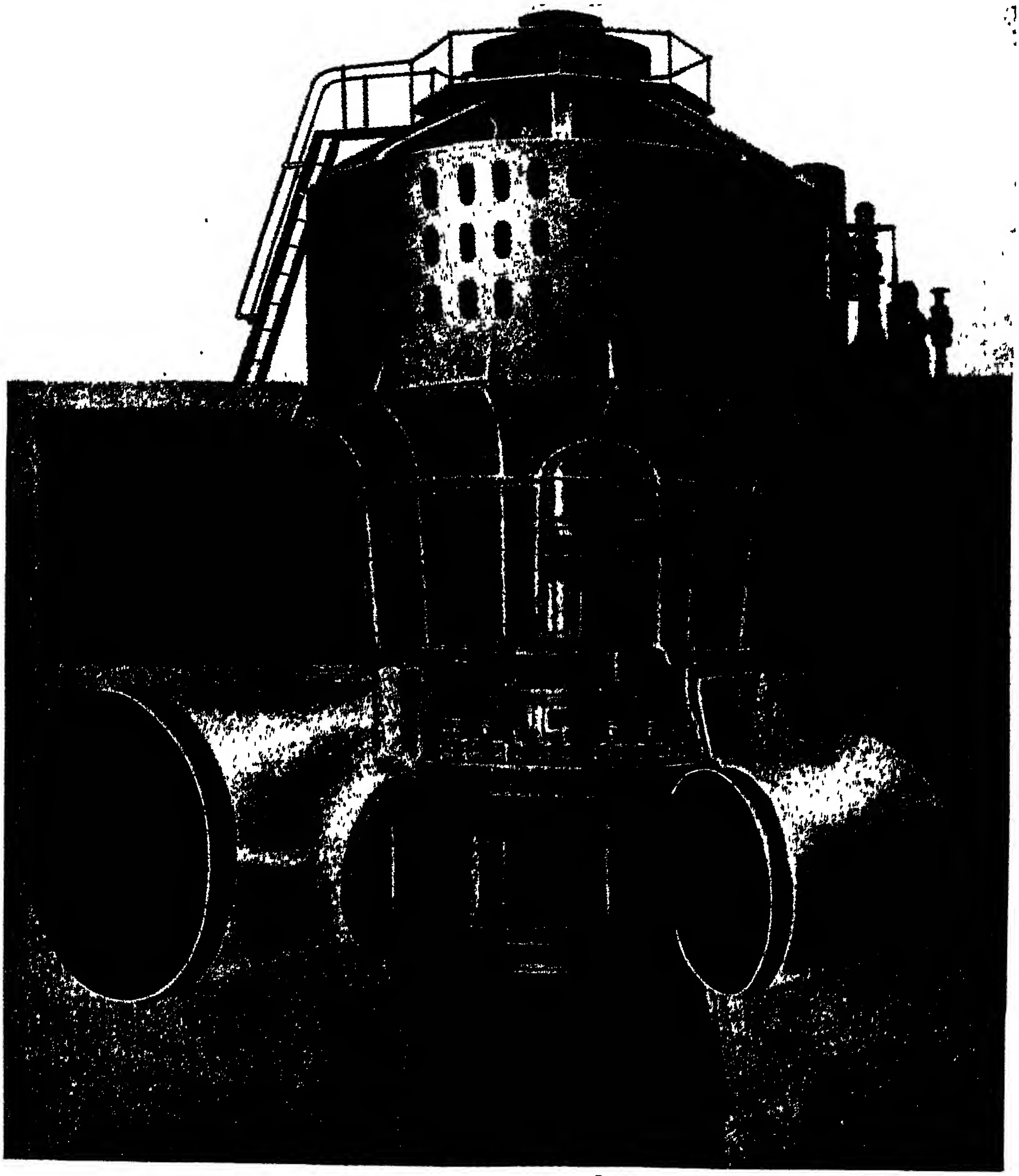
As the party were approaching the great Continental Divide from the east, by way of the State of Montana, the leaders were greeted with picturesque and wondrous stories of the great falls which were to be found upon the Missouri River. They could not miss or mistake them, so the Red Men said. For further guidance and to support their asseverations, the Indians resorted to their characteristic,

quaint, yet lucid methods of description—an eagle's nest at one of the falls would attract the explorers' attention. The Roamers of the Plains did not prevaricate; in due course the diligent trampers espied the home of the monarch of the air, and the fact is duly recorded in the journal—"Just below these falls is a little island in the middle of the river, well covered with timber. Here on a cottonwood tree an eagle had fixed its nest and seemed the undisputed mistress of a spot, to contest whose dominion neither man nor beast would venture across the gulfs that surrounded it."

The explorers promptly christened this tumble in the Missouri River, Black Eagle Falls, from the eyrie of the bird near by. But rambling along this noble waterway they found other and more imposing cataracts, the largest of which, from its supremacy, they christened the Great Falls. The other cascades in the vicinity were named respectively Coulter Falls after a member of the party, Crooked Falls from the sinuous character of the ledge forming the river bed at this point, and Rainbow Falls from "the masses of white foam upon which the sun impresses the brightest colours of the rainbow."

CANYON FERRY DAM AND POWER-HOUSE.
This station, of 7,500 kilowatts capacity, was built in 1898 to supply electricity to the Helena district 17 miles away.

It was early in July, 1805, that the explorers alighted upon these wonders of Nature, and although their picturesque narrative provoked profound interest, yet, for nearly one hundred years, the cataracts were regarded as merely worthy of inclusion among the spectacular side-shows of Nature. The possibility of turning them to economic account did not occur to anyone except that imaginative and daring western railway pioneer, James J. Hill. Convinced that some day the commercial value of these waterfalls would be appreciated, he persuaded his colleagues



By courtesy of the Westinghouse Electric International Company.

HOW HYDRAULIC POWER IS CONVERTED INTO ELECTRICAL ENERGY.

Sectional view of a vertical water-wheel and generator. The water, coming from the penstock, enters the tube on the left, rushes round in the horizontal plane, and plays upon the vanes, with the result that the wheel is set in motion. The water passes to the centre of the wheel to fall inert through the connecting draft tube into the tail-race below. From the upper part of the turbine-casing projects the vertical shaft upon which the revolving part of the generator is mounted.

to co-operate with him to secure their ownership.

When, twenty years later, the possibilities of hydro-electric energy dawned upon the commercial world, and it was decided that these cataracts should be harnessed, James J. Hill concluded that it was a task for much younger men than himself, and consequently disposed of his interest in the property.

It was the copper industry that wrought such a change in this corner of the United States. The discovery of huge deposits of the red metal in the towering hump of Anaconda, the "Richest Hill in the World," as it is colloquially known at Butte, and the establishment of huge smelters to treat the ore drawn from the vast honeycomb of workings upon which the city now stands, and other mines in the vicinity, imposed a huge demand for power. Yet the industry did not adopt the idea of drawing electrical power from the turbulent waterway traversing the state; it was content to raise steam with coal brought in from the collieries hundreds of miles away, and to shoulder the charge of £18 to £20 per horse-power per year which this form of energy imposed.

The copper industry was not opposed to electric power, but at that date, the penultimate decade of the nineteenth century, long-distance transmission remained an unfulfilled dream. The caution of the mining people, therefore, was perfectly explicable; they could neither afford to take risks nor indulge in experiments.

The First Missouri Station

In these circumstances the enterprising combines who were grimly determined to demonstrate the possibilities of hydro-electric energy, and convinced that the day would come when electricity would reign supreme throughout the copper country, decided to establish a station upon the Missouri River. For this purpose the Great Falls Water-Power and Townsite Company, which had acquired the whole of James J. Hill's rights in the Falls, set out in 1890 to create the initial generating station by harnessing the Black Eagle Falls. Thus was launched the first scheme for the commercialization of the cataracts upon this waterway discovered by Lewis and Clark in 1805. Furthermore, it represented the first steps of what subsequently developed into a comprehensive scheme for the exploitation of the whole of the tremendous energy running to waste at this point—a project which, though persistently developed during the past 31 years as exigencies favoured, has not yet been carried to its logical conclusion.

Three Forks Confluence

The Missouri River comes into being under this name at the point where the Jefferson, Gallatin, and Madison meet, the confluence being appropriately known as Three Forks. The river then follows a sinuous course, and describes a huge elbow turn before striking due east to meet the mighty Mississippi. About 100 miles below Three Forks it makes its first abrupt descent in the Black Eagle Falls near the town of Great Falls. Three and a half miles beyond it falls abruptly for 80 feet in the three big steps of Coulter's, Rainbow, and Crooked Falls. The river continues to fall steadily, though somewhat sharply, 140 feet in the course of the next 4½ miles, when it describes a sudden vertical and spectacular plunge of 77 feet, forming what is known as the Great Falls of the Missouri, the most stupendous single drop in the course of the 3,047 miles' flow of this waterway. In the short length of eight miles between Black Eagle Falls and Great Falls the river drops no fewer than 400 feet; intervening rapids supplement the descents represented by the outstanding four cataracts, giving a flow of water which, translated into energy, provides 76,000 continuous horse-power under low-water conditions.

The hydro-electric subjugation of the Black Eagle Falls represented not only the first important development of the natural descent of the Missouri River, but also constituted the first determined attempt to exploit hydraulic energy in the State of Montana. By throwing a timber crib dam, filled with rock, in a curve across the waterway, the level of the river was lifted to 44 feet. This dam was secured to each

bank by means of a masonry abutment, and a power-station was built on each side. That on the north bank developed 8,000 horse-power, and was wholly absorbed by the copper ore reduction works alongside. The smaller station on the south bank furnished power for lighting, and for operating the tram-cars in the city of Great Falls two miles away, as well as meeting the energy requirements of a neighbouring milling company. It will be observed that all the power, with the exception of that furnished to Great Falls, was consumed on the spot so that the question of long-distance transmission did not arise; the line to the adjacent city was, of course, quite short.

The success of this initial undertaking prompted other combines to participate in the development of hydro-electric energy in this territory. Among these was one created to secure an eligible site at Canyon Ferry on the Upper Missouri River, about 50 miles below Three Forks, and some 17 miles east of Helena. At the crossing of the river, which at this point is pressed into a narrow channel by the opposing banks, a timber crib dam, filled with rock, 490 feet in length, with cut-masonry abutments, and 40 feet in height, was built, together with a forebay feeding the water into the power-units accommodated in the building at the foot of the dam. The conditions were favourable to the rapid completion of this undertaking, and power-supply commenced in 1898. The generating installation comprised ten horizontal water-wheel units and vertical generators having a combined output of 7,500 kilowatts. A transmission line, 17 miles in length, was built to carry the current at a pressure of 11,000 volts to Helena, where it was used for lighting and general power purposes. Although a relatively small station, the reliability of its service led to the receipt of a demand for power from Butte, with the result that in 1901 duplicate transmission lines, carrying current stepped-up to 66,000 volts, were led to the last-named city.

Canyon Ferry—Helena Development

Seeing that Helena was to receive electrical energy generated 17 miles away, Butte resolved not to be left behind. Accordingly, about the same time as the Canyon Ferry station was taken in hand, another enterprise, the Butte Electric and Power Company, decided to complete a similar station for its own centre. Investigations revealed that the most favourable situation for the first hydro-electric station designed to meet Butte's specific needs was at Big Hole, on the river of that name, 22 miles to the south-west. Here a timber crib rock-filled dam was built to give a 65-feet head of water, and, incidentally, to form in the canyon a storage reservoir 3½ miles in length. This undertaking was completed about the same time as the station serving Helena. Although it is a smaller installation than that at Canyon Ferry, the power-house, at the foot of the dam, equipped with four water-wheel driven generators, which have a total capacity of 3,000 kilowatts and produce current sent over the double-circuit line at 15,000 volts, proved to be valuable for supplying the peak-load demand for the lighting system in Butte, and for the maintenance of 1,600 horse-power to the city's water-supply pumping-station about a mile below the power-house.

Butte Launches Out

The enlargement of the station at Canyon Ferry in 1901, stimulated the Butte Electric and Power Company to embark upon another enterprise on the Madison River, a few miles south of Three Forks; while a rival company essayed to construct another station at Hauser Lake. The last-named proved to be an ill-starred venture. A dam was built, but unfortunately it collapsed, and the company responsible for its construction fell with it. It was anticipated that the provision of Canyon

CREATING AN ARTIFICIAL WATERFALL UPON THE MISSOURI RIVER—THE BUILDING OF THE HOLTER DAM, AND TEMPORARY CONSTRICTION OF THE WATERWAY ON THE LEFT.

Having harnessed the natural cataracts, the engineers of the Montana Power Company threw a barrage 1,350 feet long by 100 feet high across the Missouri, and created a storage reservoir of 60,000 acre-feet. The entire head of water is used to develop 40,000 kilowatts.

Ferry station would satisfy the increasing demands from Helena, and Butte, again determined not to be lagging, supported the Madison project. The rivalry between these two centres stimulated general interest in the whole issue of hydro-electric energy and encouraged development.

The Madison River Station

The Madison power-station was built in the Lower Madison Canyon about 60 miles south-east of Butte, at a point where the river becomes decidedly constricted by the towering walls of the ravine. A timber crib dam, filled with rock, was built from cliff to cliff; the length of this impounding work was 183 feet; while, by being carried to a height of 44 feet, it threw back 36,000 acre-feet of water to form a storage reservoir. The power-house was placed at a point lower down the canyon; the water was led thither through a wood-stave pipe, 10 feet in diameter, laid on the levelled rock grade and supported in iron cradles. The water actuated two horizontal turbines placed in open cylindrical steel tanks set outside the power-house, and connected to two 1,000-kilowatt generators in the building.

This source began to furnish Butte with additional power in 1901, but five years later, demands for further energy being received, a second power-house was taken in hand in the canyon. The new building was erected about 1½ miles below the dam, the point selected giving a head of 110 feet. The water was led from the lake supplying the original power-house through two additional wood pipe-lines laid side by side, and delivering into an open concrete pressure chamber built into the cliff face above the station. From the pressure chamber the water is carried through four steel penstocks, each 9 feet in diameter, to the four horizontal water turbines coupled to 2,500-kilowatt generators in the station.

When this second station was completed in 1906 the original power-house was brought up to date; the total volume of energy from these two stations is now 12,000 kilowatts. The power is stepped-up to 110,000 and 50,000 volts respectively for delivery to Butte, and also to other towns in the State of Montana. About this time three other small plants were put in hand in the district. Two are on the Yellowstone River, at Livingston and Billings respectively; the capacity of the former is 1,500 kilowatts and that of the latter 1,080 kilowatts. The third station, only of 450 kilowatts, was erected at Lewistown on Spring Creek. These three stations were built to meet local demands.

The completed undertakings, although scattered and individual in character, achieved one extremely valuable object by revealing to the industrial communities of Montana that in the State's water-powers existed a servant which would render them self-contained in regard to energy. It was now apparent that hydraulically generated electricity could be transmitted over long distances without risk of interruption. The copper interests became enthusiastic supporters of water-power, which was proving so very much cheaper than steam-power.

Second Attempt at Hauser Lake

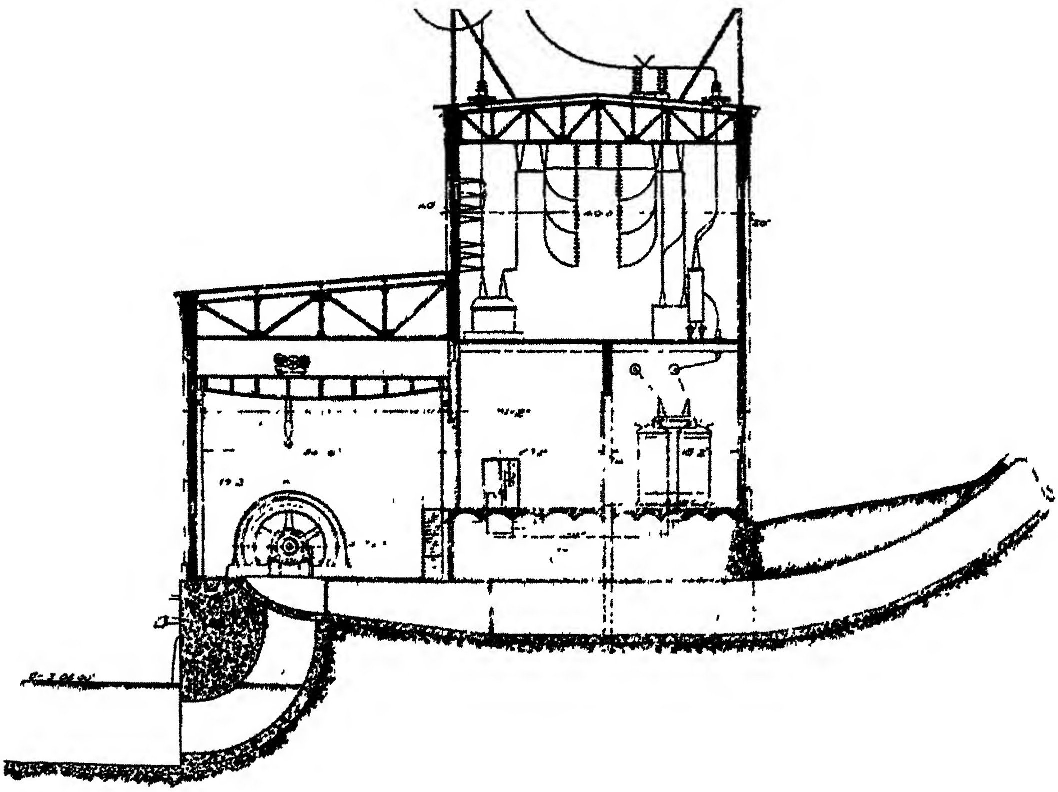
This conversion furnished the necessary stimulus for further and more ambitious development; there were two proposals which commanded widespread support. The one was the installation of a power-plant upon Hauser Lake notwithstanding the disaster which had overtaken the pioneer enterprise; the other was the harnessing of the cataracts upon the Missouri River—the Coulter, Rainbow, and Crooked Falls. This last-named enterprise was generically described as the "Rainbow Development," inasmuch as the three falls and their control were to be considered as a single scheme.

The Hauser Lake undertaking was distinctly important apart from the fact that

it offered an appreciable contribution to the electricity supply. This lake is a widening of the river, commonly experienced upon American waterways owing to the opposing cliffs falling back, so that an enlarged basin is left for the water. Much of the low-lying land is submerged at flood period, and left high and dry when the water is low. It was realized that the conditions favoured the conversion of this depression into a storage basin.

One of the factors in this decision was the urgent necessity to secure more control over the flow of the river, so that the difference between flood- and low-water levels would be rendered less marked.

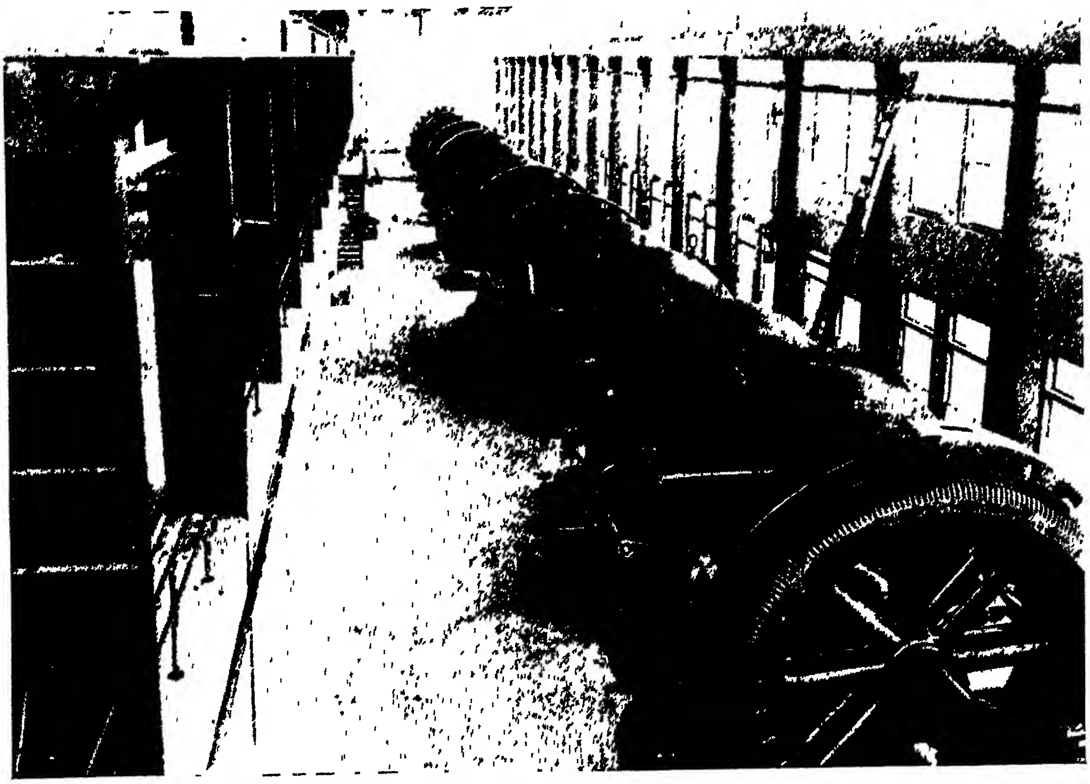
The site selected for the erection of the necessary barrage was at the spot where the river is hemmed in by the somewhat sudden closing of the opposing cliffs. Even this favourable convergence demanded the erection of a massive concrete dam 720 feet in length by 65 feet in height. In this way the water was impounded to such a degree as to be backed up the river for a distance of 14 miles to the tail-water or discharge from the Canyon Ferry power-house. Thus was formed a huge storage reservoir 46,000 acre-feet in area, which may be drawn upon to regulate the flow of the river. Control over the level of the lake and water is secured by means of a concrete flash-board structure, 14 feet in height, crowning the crest of the dam, and forming a spillway for the surplus during periods of flood.



SECTIONAL ELEVATION THROUGH THE RAINBOW FALLS POWER-HOUSE.

Showing pipe-line delivery to turbo-generator and draft-tube connecting with tail-race. On the right the lower floor carries the transformers and other auxiliaries; above, the high-tension room houses the switches and connexions to the 110,000- and 50,000-volt transmission line terminals on the roof.

The power-house is placed at the foot of the dam, level with the river. Behind and above this building is a massive concrete-



WHERE THE WATER DIVERTED FROM THE RAINBOW FALLS DISSIPATES ITS ENERGY TO PRODUCE ELECTRICITY

The eight horizontal units operate under a head of 112 feet, and have a total capacity of 35,000 kilowatts.

lined channel, forming the forebay whence the water is led to the turbines. The generating equipment comprises six water-wheel units directly coupled to six 3,000-kilowatt generators; the total capacity of the station is thus 18,000 kilowatts. The current is transformed to 66,000 volts for transmission over duplicate lines to East Helena, where it forms a junction with the lines coming in from Canyon Ferry, and thereby becoming available for transmission to Butte as well as to Helena.

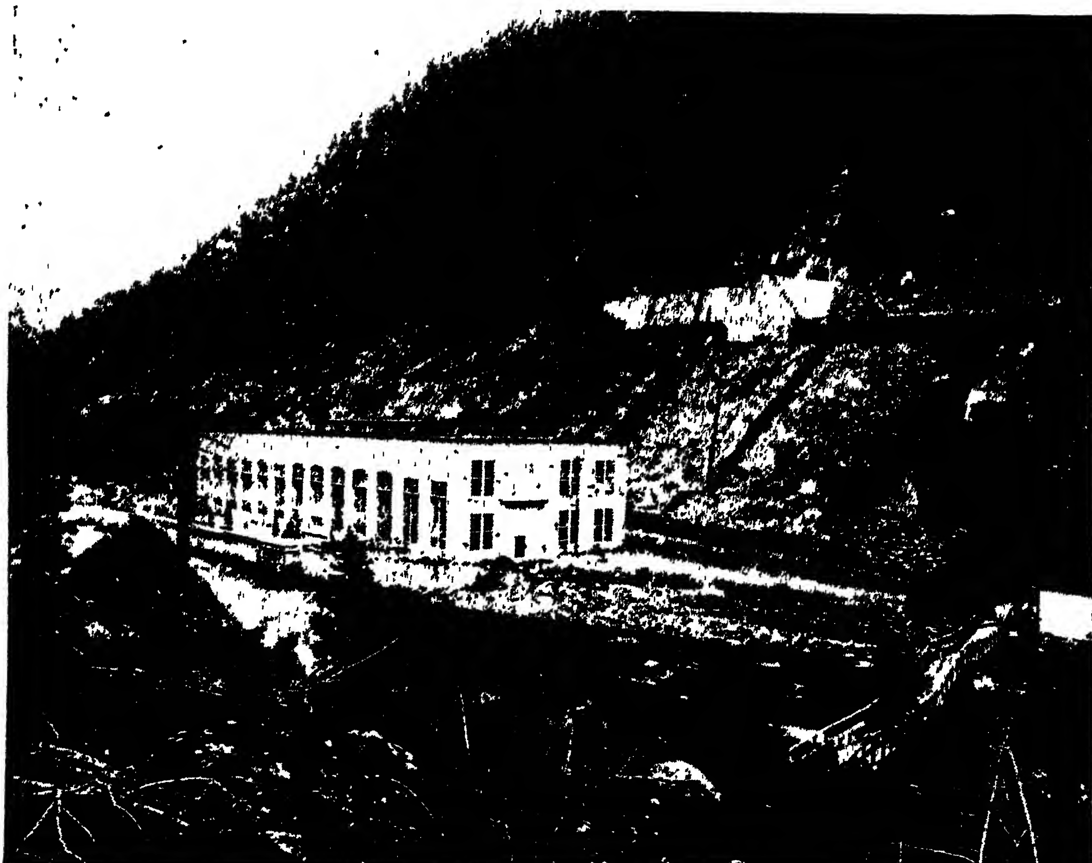
The more pretentious "Rainbow Development" embraces the exploitation of the water tumbling over the Coulter, Rainbow and Crooked Falls. This scheme, begun in October, 1908, and completed within two years, mainly owes its speedy fulfilment to the vigorous enterprise of Mr. John D. Ryan, the presiding genius of the Great Falls Power Company. As a preliminary step, this company had already secured the Black Eagle Falls undertaking, so that it was in possession of all the water-power rights in the Missouri River from the Black Eagle to the Great Falls eight miles below.

To harness the Rainbow Falls an A-shaped timber crib dam, filled with rock, 1,146 feet in length and 29 feet in height, having massive concrete abutments and sluice gates, was thrown across the river on the crest of the falls. The barrage is built upon solid rock, a coffer-dam having been erected across the waterway to permit its construction. The up-stream side of this structure is given such an angle as to ensure the unquestioned stability of the dam under all and varying conditions. In times of flood to which the Missouri is exposed, the volume of water passing down at such periods is occasionally remarkable. The higher the flood and the greater the

pressure of water, however, the more stable becomes the dam, because the weight of the water holds it down. On the down-stream side the slope tapers off into a long apron keyed to the rock of the river bed to take care of the overflow without precipitating shock or commotion and without contributing to erosion of the bed-rock.

At the south end of the dam is a sluice-way with a discharge of 8,000 cubic feet of water per second; its flow is controlled by hand-operated gates. At the opposite—north—end of the dam are the two intakes for the pipe-lines, each 15 feet 6 inches in diameter. These carry the water 2,400 feet down-stream to a balancing reservoir set on the top of the hill above and behind the power-house, which is placed at the water's edge below Crooked Falls. This reservoir, covering 2 acres, is excavated out of the solid rock and has massive concrete walls keyed to the solid foundation offered by the hill. At the lower end it is provided with a weir which takes care of any over-flow such as might occur with any sudden rise of the water-level in the reservoir. Along the side facing the power-house there are twelve openings, fitted with gates and screens, which pass the water through 8-feet branch penstocks to the power equipment.

The total head of water obtained in this manner is 112 feet. The original installation comprised six inward flow Francis turbines, having two runners on a horizontal shaft, and normally developing 6,000



DRAWING 12.000 KILOWATTS FROM THE MADISON RIVER.

Two power-houses, of 2,000 and 10,000 kilowatts capacity respectively, are set in the Lower Madison Canyon. The No. 2 power-house, illustrated above, is 7,500 feet down-stream from the dam. The water makes its final journey to the turbines through four 9-feet penstocks. On the hill-side may be observed defences against falling rock and snow-slides.

horse-power each, controlled by Lombard governors. Each wheel is directly coupled to a General Electric alternating-current generator, rated at 3,500 kilowatts, 6,600 volts, three-phase 60 cycles at 225 revolutions per minute, complete with exciter. When the equipment was installed two of the generating units were reserved for the supply of power to the Great Falls district four miles away. The power was transmitted at the generator voltage of 6,600 volts, but the output from the four remaining units was transformed to 102,000 volts and so transmitted to Butte and Anaconda, 130 and 152 miles away respectively.

Owing to the increasing demand for power, in 1916 it was necessary to modify and enlarge the system. Two additional generating units, each of 5,000 kilowatts capacity, were installed, and additional head-works and pipe-lines were laid down to serve them. In this way the output of the station was increased to 35,000 kilowatts. The whole of the generating supply was then stepped-up, a proportion to 50,000 volts for transmission to various outlying mining and industrial districts, and the balance to 110,000 volts to meet the additional requirements of the mining and smelting interests at Butte and Anaconda.

By the time the Rainbow hydro-electric plant was brought into full working order, the mines and ore reduction plants in the Montana districts had become fully convinced of the great economies arising from the use of electric power. Their charges under this heading had been reduced from £18 and £20 with steam to approximately £10 per horse-power per year. Such a big cut could not fail to exercise a far-reaching influence upon the hydro-electric problem; a safe system had been evolved which favoured the provision of adequate stations at several points on different rivers, and the whole had been interconnected by a complete transmission network.

THE HYDRO-ELECTRIC INSTALLATION AT THE HAUSER LAKE POWER-HOUSE
Six horizontal water-wheel units and generators with a combined capacity of 18,000 kilowatts.

Talking Across a Continent

THE ROMANCE OF AMERICAN LONG-DISTANCE TELEPHONY WHICH DEVELOPED IN 1876 FROM A SCOTSMAN'S EXPERIMENT WITH 100 FEET OF COPPER WIRE

"MR. WATSON! Come here — I want you!"

What a commonplace summons from one room to another across a telephone. How often is a similar summons uttered every day in thousands of buildings in every town and city throughout the world. But in no case is the reply so prompt as it was upon that memorable afternoon of March 10th, 1876. Scarcely had the words been uttered when a door was flung open, and excited feet ran up a narrow communicating staircase, two steps at a time, to the excited accompaniment of "I heard you! I could hear every word you said!"

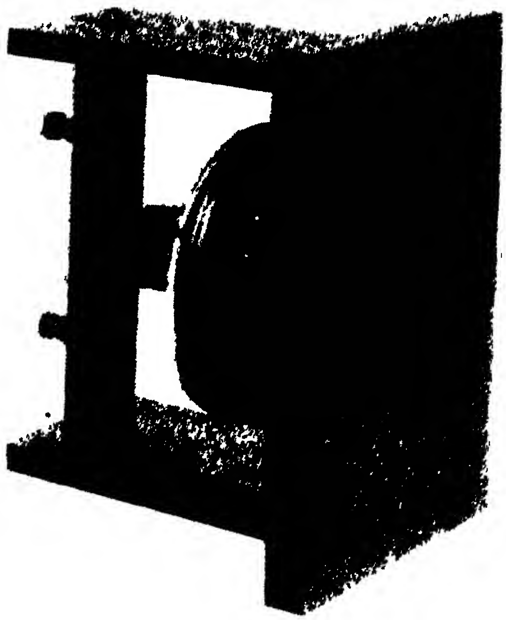
The words were the first to be spoken into and heard across a thin copper wire, barely 100 feet in length. It was the triumphant culmination to months of patient and diligent experiment, pursued alternately in cellar and attic in the American city of Boston by Mr. Alexander Graham Bell and his colleague, Mr. Thomas A. Watson, often until the wee sma' hours of the morning.

*   *   *   *   *

"Hoy—hoy! Mr. Watson! I want you. Can you hear me?"

This time there was a merry responsive chuckle, followed a moment later by the comment, "Yes, Dr. Bell, I hear you perfectly!" Upon this afternoon of Monday, January 25th, 1915, some 3,400 miles separated the two speakers. The telephone line, barely 100 feet in length in 1876, had grown, in the course of some forty years, into a long-drawn-out spider-like thread across a continent, bringing the Atlantic into talking-touch with the Pacific seaboard.

The story of the telephone and the perseverance of Bell, the Scotsman, and of his mechanical and electrical colleague, Watson, constitutes one of the most fascinating romances of invention. In the light of the contemporary attitude maintained towards the telephone, and its universal recognition as an indispensable handmaid to the community of to-day, it is amusing to recall the reception which greeted its appearance some forty years ago. In the endeavour to convince a sceptical world, Bell and Watson toured the eastern American States, after the manner of itinerant lecturers, giving demonstrations in any building which happened to be available. But the world would have nothing to do with the idea.



BELL'S FIRST TELEPHONE.
It is of a type generically known as the "Gallows."

ACROSS THE SALT-SINKS TO THE SNOWS OF THE SIERRAS

The telephone engineer followed a bee-line through this forbidding country. The white patches upon the ground are stretches of salt left by the evaporated water.

The American press ridiculed the inventors mercilessly. So indifferent was the public attitude towards this manifestation of fertile thought, that those who had acquired the sole rights to exploit the new idea in New York City and its environs, promptly parted with their concession for £4,000, and concluded that they were well rid of a bad bargain.

It was only the inventors' unswerving faith in their achievement, shared by one or two close friends, that secured adequate financial assistance to keep the invention alive. When the patent was sixteen months old there were only 778 telephones in use. The first company was remarkable in that it was rich in unshakable confidence and unbounded enthusiasm, but deficient in capital. Had it not been for one staunch supporter, Mr. Thomas Sanders, the father of one of Bell's deaf pupils, it is doubtful whether the invention would ever have been commercially developed. Sanders risked the whole of his fortune in backing the initial enterprise, and clung tenaciously to it during its darkest days.

The turning point in the fortunes of the telephone came when Mr. Theodore N. Vail was persuaded to bring his powers of organization upon the problem. Upon taking the helm the new director promptly realized why the invention failed to make more than slight headway in the world of affairs. Those associated with its welfare had regarded development from too narrow an angle. They had set out with the notion that it would never be regarded as more than a local amenity, and so had endeavoured to establish individual self-contained installations. Mr. Vail viewed its future from an entirely different standpoint. He saw in the telephone the means wherewith to weave scattered towns and cities into a vast homogeneous, intercommunicating whole.

Such an end was attainable in one way

only—the establishment of what we now call " trunk " lines, or, as they are described upon the American continent, long-distance 'phones. His first step in this direction was to link Boston with New York, which sufficed to convince him that his method of reasoning was correct. Business men of the two cities, as well as of the towns along the route, promptly recognized the saving of time and money which such communication afforded.

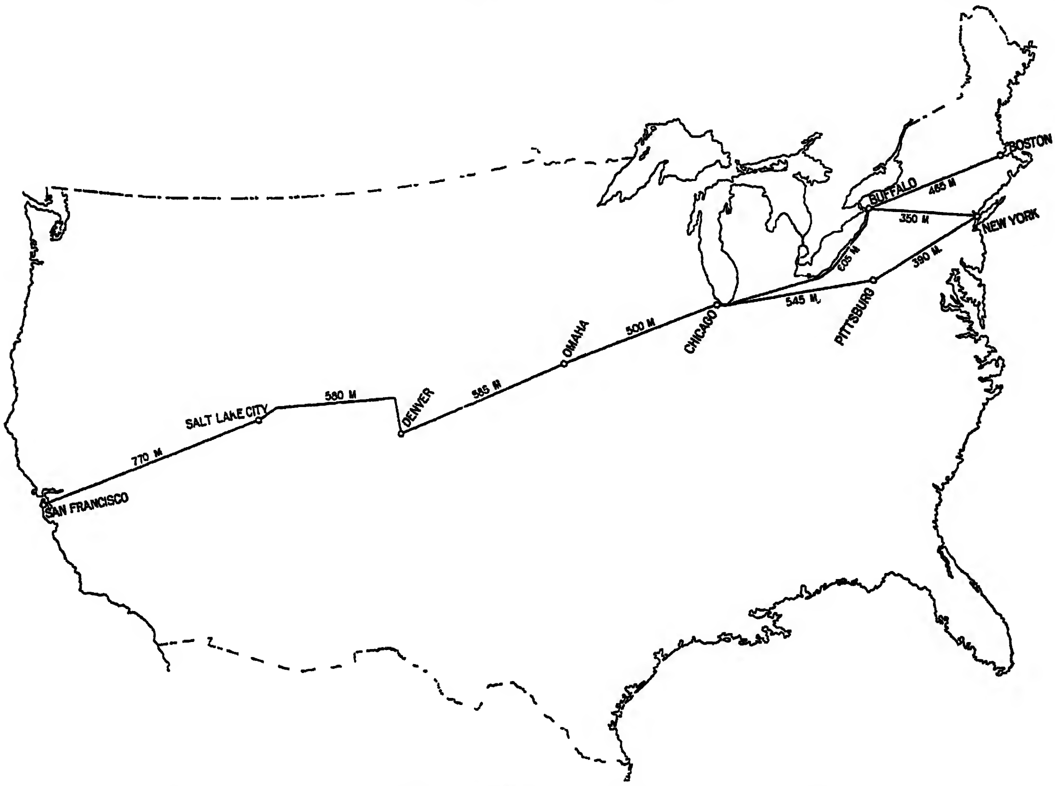
Elated with his initial success, the mastermind now set out to bind together in a similar manner all the leading big eastern centres. In this way the trunk roads crept northwards, southwards and westwards from the Atlantic seaboard, and finally reached as far as Pittsburg, a distance of 390 miles from New York City. Heavier and more remunerative traffic accompanied the completion of each successive trunk stage. This circumstance induced the directing genius to at once embark seriously upon an audacious scheme of spanning the continent by the frail thread of copper wire.

The first stage of the direct transcontinental line was opened by Mr. Bell on October 18th, 1892, by conversation across the line carried from New York City to Chicago. These two cities were thus brought together by tacking an additional 545 miles to the New York-Pittsburg line; the actual talking distance measured just 935 miles of wire. At the time the line was inaugurated, it ranked as the longest trunk telephone in the world.

During the construction of this section doubts were expressed as to whether there would ever accrue sufficient traffic to render it profitable; and the experience of the first few months certainly tended to confirm the contentions of the pessimists. The traffic was disappointing and the line so unremunerative as to become colloquially known as " Vail's folly ! " The indefatigable Vail ignored such criticism,

POLE-SETTING CREW LEAVING CAMP.
Motor trucks were largely used for constructional work amid the mountains of western Nevada, as horses are speedily exhausted by the extremely saline air.

and set out to ascertain for himself why failure had occurred. He speedily discovered the reason. The impression had gained ground that communication was uncertain and indifferent; the citizens of the two cities had allowed themselves to be persuaded that conversation could not be maintained across 935 miles as easily and efficiently as across 100 miles of wire. To dispel these false ideas, an elaborate scheme of propaganda and demonstration was launched in the terminal cities, with the result that traffic in rapidly increasing volume gravitated to the line, and to-day the New York-Chicago long-distance telephone is one of the busiest and hardest-worked links of this character in the world.



THE WAY OF THE WIRE FROM NEW YORK TO SAN FRANCISCO

The 3,370 miles' stretch of transcontinental line. By interconnection at the western end it is possible to talk between New York and Vancouver.

Chicago once having been impressed with the commercial value of the long trunk wire, the advance across the prairie provinces was launched. The first objective was Omaha, on the Mississippi, 500 miles west of Chicago, and this was duly coupled up. Then the next big stride of 585 miles to the capital city of the State of Colorado was taken. When the call "Hello, Denver!" was given from New York for the first time, the talking span of wire had been stretched out to 2,020 miles.

One half of Mr. Theodore Vail's dream was now fulfilled, and for a time he rested content. Beyond Denver City rose the ragged lofty Rocky Mountains through which the passes are few and far between. And then, beyond the continental mountain backbone rolled the vast stretches of arid, blistering alkali desert where human activity is scarcely to be found, to the second mountain range, the Sierra Nevadas, almost as forbidding as the Rockies.

It was the stretch between Denver and the Sierras which was the deterrent. With the exception of Salt Lake City there was

no big centre to be threaded during the last lap of 1,350 miles. Local traffic would be virtually negligible, at least for many decades to come, for the simple reason that the country has been consistently shunned by the farmer, the settler, the miner, and other pioneers of development.

While the engineering difficulties were certainly imposing and perplexing, curiously enough it was neither the hostility of Nature nor the lack of traffic *en route* which compelled the halt, but the task of coaxing the human voice to make the final jump.

To-day we pick up the receiver and talk to our friend with as much unconcern as we pen a letter. We know that the transmission of speech across a wire is due to electricity, and that the central battery system is in universal vogue to-day, but we are prone to be content with just this information. Yet the amount of electricity dispatched through a telephone circuit is infinitesimal. In his *History of the Telephone*, Herbert N. Casson relates that the volume of energy released by cooling a spoonful of water by only one degree would suffice to operate a telephone for ten thousand years.

Transmission of Speech

Sound, as is well known, is due to vibrations of the air. When we speak into a telephone transmitter the vibrations, corresponding to the sounds of the syllables of the words we utter, strike against a small metal disk—the diaphragm—and in this way become converted from air into electrical vibrations. Each electrical vibration or wave is extremely delicate and distinctive; it differs from its neighbours as much as one pebble on the beach differs from all its fellows.

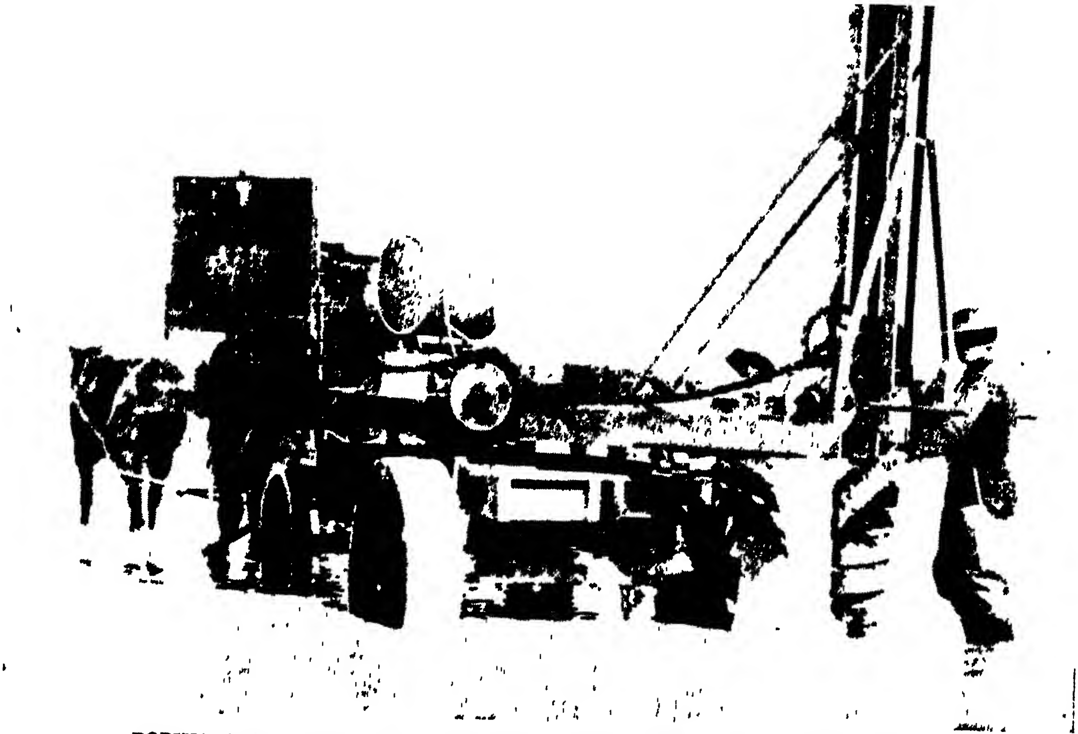
During its transit through the wire the individual form of this wave must be preserved, as well as its relationship to all the others. The vibrations must not crowd and jostle one another to the slightest degree; nor must they impede one another. They must reach the opposite end of the line in precisely the same formation, the same shape, and at exactly the same interval in order of sequence as they leave the transmitter. Upon gaining the receiver the electrical vibrations are converted back into their relative sound waves. Thus the listener can hear clearly and distinctly the words articulated at the opposite extremity of the wire.

As may be imagined, these waves travel at a tremendous velocity; they hurtle across the wire at the incredible speed of 56,000 miles per second. The result is that the telephone not only transmits speech, but carries it thousands of times faster than its natural speed. Some idea of what a velocity of 56,000 miles per second really means may be conveyed. Sound travels at the rate of 1,111 feet per second. If one were to ascend to the roof of a New York sky-scraper and, facing westwards, were to shout "Hello, San Francisco!" presuming that a voice could have sufficient capacity to reach the Pacific coast, the words would not be heard at their destination until four hours after they had been uttered. Call the same words over the transcontinental telephone wire, and they are heard instantly.

Speed of Electrical Vibrations

A current of such feeble intensity and of such low power of resistance, can be disturbed, even quenched, by the slightest imperfection or obstruction. When it is remembered that every minute, while conversation is in progress, millions of electrical waves are being created, dispatched, and received, the wonder is that they reach their destination in such an orderly manner as to be reconvertible into comprehensive speech which can be heard without the least effort.

It is a failing of human nature, when a telephone line evinces signs of being somewhat indisposed, to shout into the transmitter with all the power the voice can



BORING THE HOLES FOR THE POLES ACROSS HUMBOLDT LAKE, NEVADA.
This dreary sheet of water is about 5 miles in length by 5 miles in width. For the support of the wires 80 poles had to be planted, in 18 to 24 inches of water, for a distance of 2 miles.

command. Such effort represents merely so much wasted energy. The frail wave peculiar to the telephone refuses to be intimidated in such a manner; it becomes no more intense than when conversation is conducted in a normal tone, so long as the articulation is clear.

Telephony is merely a straightforward illustration of certain electro-mechanical phenomena. The voice sets up vibrations of the air; these, impinging upon the diaphragm, become translated into electrical vibrations, and upon striking another diaphragm once more become resolved into air-waves. Finally, the electric current for telephony cannot be intensified beyond a certain degree; if it is so forced, it refuses to transmit speech.

The problem, from the telephone technician's standpoint, was to preserve the shape and formation of the waves and to persuade them, after covering a round 2,000 miles without growing tired, to continue the distance travelled for a further 1,300 miles.

The achievement of a Serbian scientist at length solved the problem of telephoning for enormous distances with perfect success. Dr. Michael Idvorsky Pupin, a professor at Columbia University, was attracted, as hundreds of other savants have been, to the telephone and its peculiar and complex problems. Long-distance telephony was the phase which appealed to him, and he embarked upon a series of elaborate experiments, the outcome of which was the device known as the "loading coil," which exercises the self-same broad effect upon the frail electrical wave travelling across the telephone wire as the relay used in telegraphy.

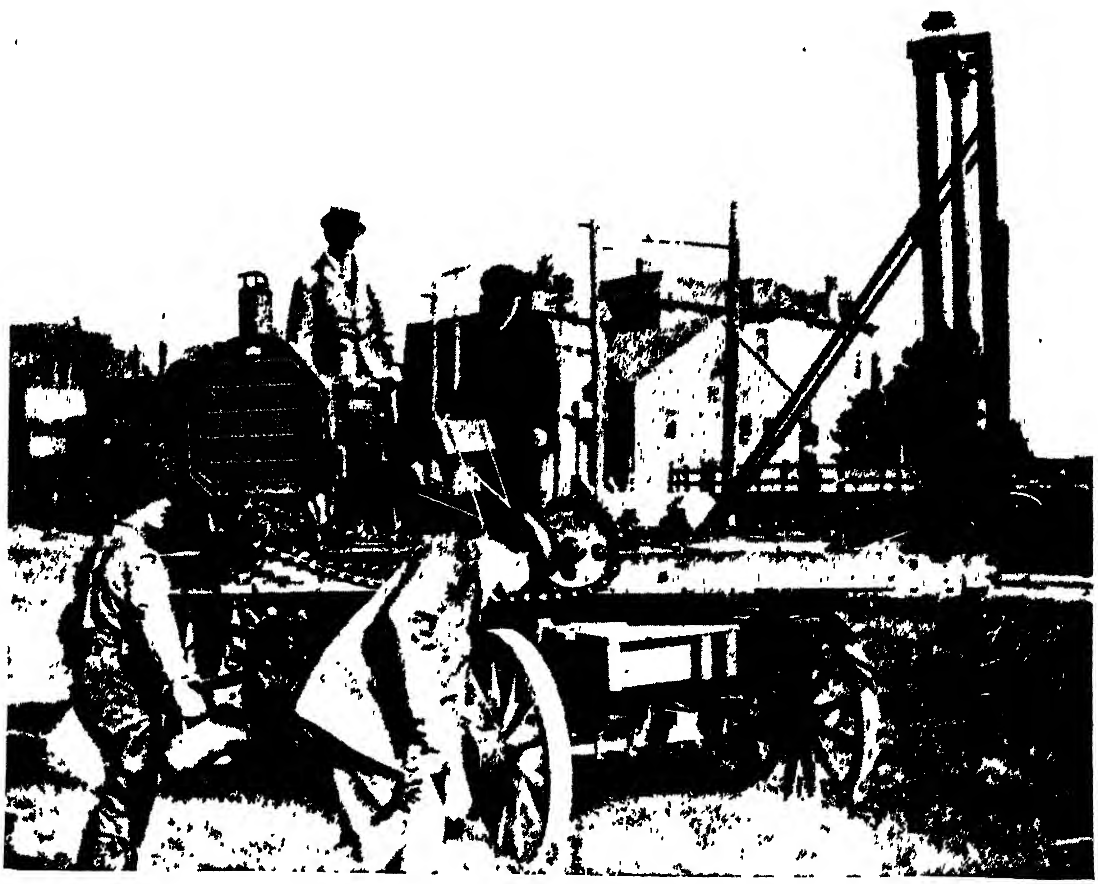
Upon the perfection of his device, Dr. Pupin gave a demonstration to many of his learned contemporaries, after the manner of scientists in communicating the results of their labours to one another.

The epoch-making invention came to the notice of Mr. Theodore Vail, who, realizing that here was the key to his great project, promptly acquired the discovery, and at the same time enlisted Dr. Pupin's enthusiastic interest in his scheme.

When at last the report of the technicians stated that the hitherto baffling problem of carrying the human voice between the two opposite seaboards was now commercially practicable, instructions were issued to close the outstanding breach in the wire link between the two oceans.

The engineer was not so dismayed by the mountain stretches as by the intervening desert belt. True, the constructional forces while labouring among the mountains were repeatedly presented with teasing problems and formidable obstacles, but the alkali desert presented problems of quite a different character. The country is sterile to the supreme degree; the only vegetation which ekes out a precarious existence is the stunted sage-brush wherein noxious animal life finds refuge. The saline sand, as fine as flour, penetrates everywhere to extreme physical discomfort. The heat is intolerable, and for the most part this extensive belt is trackless save for the railways, and their roads form the arteries for such pedestrian and other movement as may be inevitable.

Elaborate arrangements had to be made to ensure the security of the men forming the constructional gangs. Camp-trains on wheels had to be provided for their accommodation and movement,



THE POLE-HOLE DIGGING MACHINE AT WORK.
This motor-driven appliance, employed most extensively in Nevada, can dig holes for 40 poles—a mile of line—a day.

with supply bases at frequent intervals to permit revictualling. At these depots powerful mechanical tractors had to be retained because, now and again, intelligence would come to the effect that such-and-such a camp-train, while moving, had become buried up to the axles in the soft sand and was helpless. Then the tractor was hurried out to help haul the train to its next selected camping-ground.

Photograph of the electrical waves, into which the sound waves of the familiar hail "HELLO!" are converted for transmission across the wire.

Timber presented another difficulty. The poles and arms had to be fashioned thousands of miles away and conveyed by rail to points as conveniently near the route as possible; the final stages had to be covered by animal teams and tractors. Building a telephone line has nothing in common with railway construction. The railway engineer is forced to pay due regard to grades and curvature, while alignment may also be influenced by natural obstacles, such as swamps, lakes, and rivers. On the other hand, the telephone-line builder strives to carry his wire in as straight a line as possible between the two given points. Consequently, the American transcontinental trunk wire does not sweep round lakes and salt-sinks, or meander around hills and mountains. It strikes through the former and over the latter in a bee-line. In some places the builders were called upon to grope their way gingerly through waterlogged land, wading up to their thighs, or to toil up precipitous slopes, cutting a track as they advanced for the wheeled transport pressing on their heels.

Unfavourable conditions such as these do not attract labour, and the engineers of the American Telephone and Telegraph Company were compelled to give full rein to their ingenuity to accelerate construction. Many novel contrivances were evolved to this end. Among these was a device for drilling the pole-holes mechanically, especially in the worst places, such as the salt-sinks and swamps. Upon the tail of a motor tractor was mounted a vertical auger, of impressive dimensions, while the tractor served as the vehicle for the crew. Arriving at the stake planted by the surveyor to indicate the site for a pole, the tractor was manœuvred until the auger was brought over the stake. The tool was then set going to chaw its way into the soil to the requisite depth. Hole-digging in this manner enabled the worst reaches to be spanned with striking celerity; only a few minutes were absorbed in the drilling of the hole.

Then came the pole-setting crew. Previous to its appearance a horse-drawn wagon or motor-lorry had been along the route, such as it was, with the load of poles and cross-arms. The men aboard kept a sharp look out for the surveyor's stakes, and as these were reached, but without arresting the movement of the vehicle, the poles with an arm apiece were whisked overboard often to float in the vicinity of the site. When the pole-setting

squad appeared upon the scene, it had to scour round to find the pole and its arm, attach the latter, with its insulators, in position, warp the pole until its butt came to the edge of the hole, and then, with strenuous "heavo-ho!" hoist it into the vertical position, the butt settling down into its bed as the perpendicular position was attained. The auger bored a hole slightly larger than the diameter of the pole, but there was no necessity to fill the hole; whatever space remained was speedily charged with the moving silt and the saline water which acts as a preservative.

The pole set, the next process was to bear out, uncoil, and string the wire from pole to pole. For this purpose reliance had to be reposed mainly on mechanical transport. The coil of wire was conveniently mounted in the wagon to permit uncoiling as the vehicle traversed the route. The wire was dexterously yanked over the cross-arm of each pole as it was passed, to drape helplessly from pole to pole. But the wiremen were accompanied by the stringers, who, swarming the poles, drew the wires tight and made them fast to the insulators.

Details of the Line

The total length of this transcontinental telephone line is 3,370 miles, and in the run from New York to San Francisco it traverses thirteen states. There are two circuits, each using 6,780 miles of hard-drawn copper wire, 0·165 inch in diameter. By transposing these two physical circuits an additional circuit, known as a "phantom circuit," is created. Each circuit mile of wire weighs 870 lb., that is, 435 lb. for each single wire. Consequently the total weight of copper wire worked into the two circuits strung between the two oceans is 5,920,000 lb. or approximately 2,500 tons, the whole supported on 130,000 poles. In addition to the circuit wires there are the Pupin loading-coils, which are introduced at intervals of approximately eight miles. In the manufacture of these coils more than 13,000 miles of insulated wire, $\frac{4}{1000}$ inch in diameter, were absorbed.

The First Message Repeated

The line was opened by Dr. Alexander Bell, seated in New York, and, with singular appropriateness, he inaugurated transcontinental conversation with his colleague, Mr. Watson, who was in San Francisco, the first message being the repetition of the words used on that memorable afternoon of 1876. Another memory of the eventful past was revived. Upon the table at which the venerable inventor was seated stood the original "gallows" transmitter with its short connecting piece of wire used in the first field telephonic conversation over a line two miles in length—a telegraph wire was impressed for the purpose—in 1878. Although the first transmitter bears every imprint of the pioneer, it speaks volumes for the soundness of its design, workmanship, and efficiency to relate that, when switched into the 3,400 miles circuit, conversation was maintained easily. As was only to be expected, the transmission was not quite so clear and loud as with the latest expression of manufacturing ingenuity in this field. Nevertheless, it was a quaint blending of the old with the new, and conveyed a graphic impression of the huge strides which have been accomplished in telephony during less than half a century.

The transmission of the human voice over 3,400 miles of wire did not constitute the greatest achievement of this inaugural ceremony. Mr. Theodore Vail was unable to be present, being in Florida at the time. However, he was switched into the circuit, which was thus increased to 4,500 miles, and maintained conversation with his colleagues in New York and San Francisco with as much facility as if the trio had been seated round the desk in his sanctum in New York City.

DISTRIBUTING CROSS-ARMS FOR THE POLES ACROSS THE ALKALI DESERT OF NEVADA.
The material was discharged beside the machine-dug pole-holes and bolted up on site ready for erection.

Another interesting incident in connexion with the opening of this line may be mentioned, although it did not occur until October 21st, 1915. Mr. and Mrs. Thomas Edison were visiting the San Francisco Exhibition in connexion with the Edison Day Celebration. The staff at the Edison headquarters at Orange, New Jersey, conceived the idea of participating, and decided to press the telephone into service. They prepared a special greeting to their "chief," communicating it to a disk phonograph record. But they were faced with one difficulty which promised to be insuperable. Although Mr. Edison played a prominent part in the improvement of the telephone, notably in connexion with the carbon transmitter, he had never held a conversation across the wire in his life. However, he was persuaded to break his inflexible rule upon this occasion, and so picked up the receiver of the transcontinental line to listen. He was greatly surprised by his experience; the rendition of the greeting by the phonograph was remarkably clear and distinct, although,

DEFYING THE DESERT SAND BY CATERPILLAR TRACTOR
Cook and lumber wagons, stalled in the soft sand, being hauled to the next camp site in the Humboldt Lake country.

as he confessed subsequently, "to talk across a wire 3,400 miles long on my first attempt at a telephone conversation seemed to me to be a pretty big undertaking."

The line is in constant service, both day and night, despite the fact that the charge for talking between the two seaboards is approximately £4 4s. for three minutes. But for this charge those who take advantage of the convenience between the cities of New York and San Francisco enjoy the exclusive use of a trunk wire which has cost £400,000.

The transcontinental telephone line, notwithstanding its length of 3,400 miles, represents only a small factor in a comprehensive organization which has its tentacles reaching to the uttermost corners of the country. The United States of America is undoubtedly one of the best-served countries with telephones in the world. Yet the American Telephone and Telegraph Company, which constitutes the largest individual enterprise of this character, is only one of many. There are approximately 11,000 separate telephone companies operating in the country. Of this total thirty-six are associated companies of the Bell system, that is, affiliated with the parent undertaking; 9,400 are independent companies with their stations

POLE-SETTING ACROSS HUMBOLDT LAKE

The crew of seven men worked the pole to the edge of the hole and deftly hoisted it into position. The lake is little more than a salt-swamp.

connected to the foregoing system, while there are about 1,500 independent organizations declining to extend such connexion facilities. The foregoing does not include the thousands of rural lines and associations, of which there is an impressive number; of these lines and associations about 26,000 are connected with the Bell network.

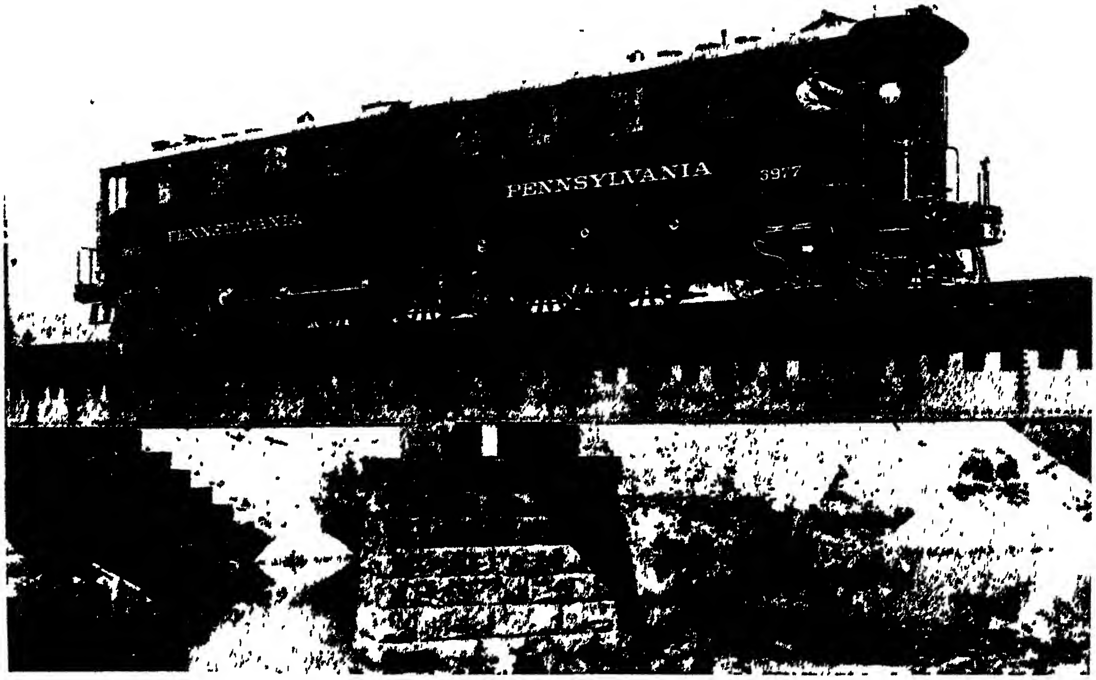
The transcontinental company owns and operates more than 12,000,000 stations. In addition there are about 900,000 stations owned by independent organizations. To maintain and operate these stations requires some 24,750,000 miles of wire, of which 3,600,000 miles are toll wire and 21,150,000 miles are exchange wire. Approximately 9,500,000 miles of wire are strung through the air on poles, while about 14,700,000 miles of wire are laid underground.

It is one of the penalties of telephone development that progress is rapid, necessitating sustained tearing out of the existing plant to make way for something superior. In the course of nine recent years the company which works the transcontinental telephone system expended the enormous sum of more than £120,000,000 sterling upon improvements.

As may be imagined, the volume of traffic flowing over such a vast intricate network of wires is immense. During a recent year more than 10,000,000,000 calls were recorded—an average of about 30,000,000 calls every day through the round twelve months. The plant necessary to handle such a vast traffic is obviously extremely valuable. According to the cost-book, it represents an investment of more than £26,000,000, but it is computed that it would cost more than £40,000,000 to instal to-day. To maintain the service requires the combined labours of about 240,000 men and women.

THE SILENT TRIUMPH OF THE FORCES OF CIVILIZATION.

Ninety miles west of the Utah-Nevada interstate boundary line the transcontinental telephone passes between the tepees and wigwams of an Indian village.



4,000-HORSE-POWER WESTINGHOUSE ELECTRIC OF THE PENNSYLVANIA RAILROAD.
This powerful locomotive, built in two units, moves the traffic through the tunnels entering New York city. It can haul a train weighing 1,000 tons up a grade of 1 in 50.

Powerful Electric Locomotives—I

SOME AMERICAN AND ITALIAN GIANTS FOR PASSENGER SERVICE

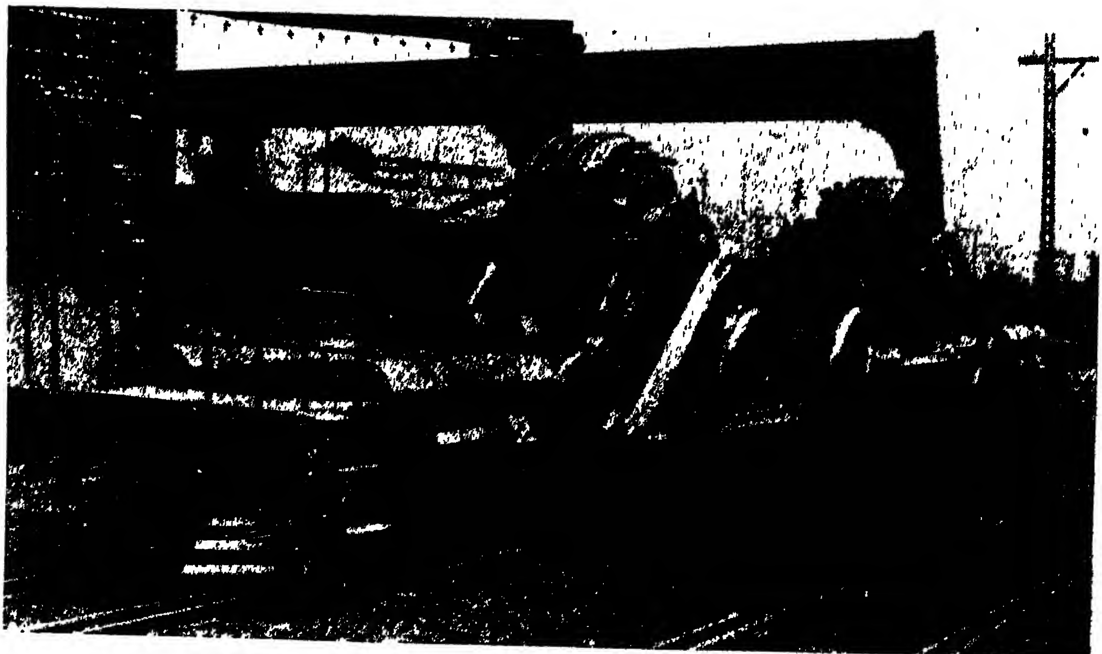
WHEN Monsieur Anatole Mallet, the distinguished French engineer, introduced his novel departure from accepted locomotive design to the railway world, it is doubtful if he visualized the remarkable influence which his idea was destined to exercise over the future trend of railway operation. The principle which he evolved, and which led to the widespread adoption of the distinctive type of locomotive bearing his name, represents the pinnacle of perfection of power-hauling, or pushing capacity.

So efficient has the Mallet proved in all ramifications of railway service that it is now generally accepted as the standard unit when formulating comparisons. This is particularly the case when discussing the relative merits, advantages, and limitations of electrical and steam practice respectively. This result is influenced no doubt by the circumstance that the railways which have embraced electric traction have been persistent and enthusiastic admirers of the Mallet for their own operations—duty which is now being taken over by the electrics.

The electric locomotive, as we know it

to-day in its huge powerful form, is essentially a product of the twentieth century. It was not until the leading trunk-lines of the world turned to electricity to secure extrication from pronounced specific operating difficulties which had arisen, and in the subjugation of which no assistance could be extended by the steam-locomotive, that development assumed the line with which we are now so familiar. Tunnel operation, where dense traffic obtains, as for instance in the approach to terminals, is neither safe, efficient nor economical under steam conditions, and this is the field in which heavy electric traction was first exploited, essentially as the remedy for the many ills which had developed and become intolerable under the old regime.

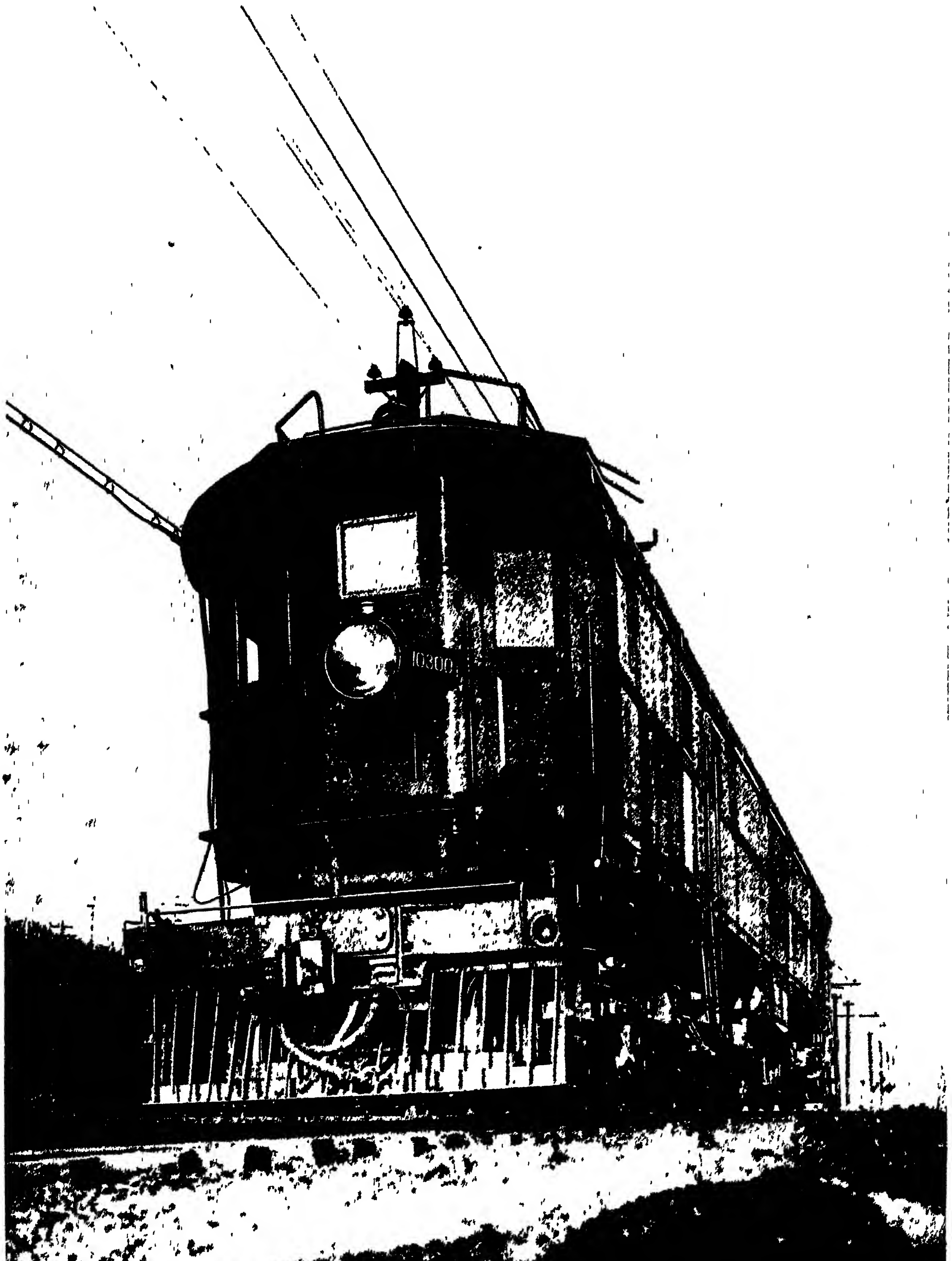
When the Pennsylvania Railroad decided to establish direct communication over its system with the heart of New York City and Long Island—a project which involved the boring of tunnels under the Hudson and East Rivers—it was obvious that electric locomotives would be required to handle the trains over this final link. As the traffic is somewhat heavy, and the conditions exacting in regard to the road, a powerful type of locomotive was urgently required to move trains of a minimum weight of 550 tons, and to start and accelerate the same upon a grade of approximately 1 in 50.



THE RUNNING GEAR OF THE WESTINGHOUSE 4,000-HORSE-POWER ELECTRIC.
Showing 2,000-horse-power motor mounted upon each bogie unit, and system of transmission to the 72-inch driving-wheels.

The design and construction of the necessary locomotive was undertaken by the Westinghouse Electric International Company, and the first of the type was produced about 1909. After being subjected to severe tests, it was found to meet the needs of the railway company so completely that an order for a fleet of thirty-three of these monsters was placed with the builders.

These electrics are of the articulated type, and consist of two semi-units permanently coupled together. The fundamental feature of the design of these giants upon the semi-unit principle may be readily understood by a familiar parallel. The result obtained is precisely the same

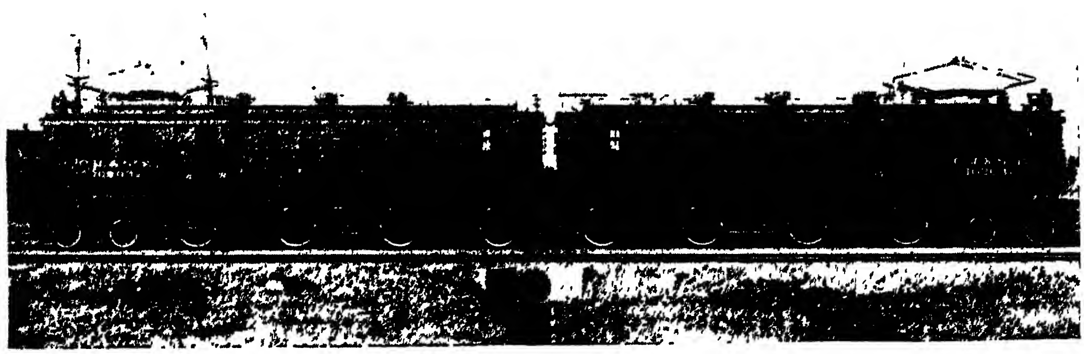


A 4,200-HORSE-POWER ELECTRIC GIANT.

Baldwin-Westinghouse locomotive, weighing 275 tons, for hauling the "Limiteds" of the Chicago, Milwaukee and St. Paul Railway through the Rocky Mountains.

as would be forthcoming if two ordinary steam-locomotives were coupled back-to-back. Each semi-unit comprises a four-wheeled bogie-truck and two pairs of driving-wheels connected by side rods, and the analogy to the steam-locomotives just mentioned is enhanced by the fact that this disposition brings the bogie-trucks at each end of the complete locomotive. Classification according to the wheel arrangements observed in regard to steam-locomotives is therefore 4–4–4–4.

The electric power equipment of each unit comprises one Westinghouse direct-current field-control, commutating-pole series-type motor, rated at 2,000 horse-power maximum. This is mounted above the driving-wheels and coupled through a system of parallel rods and cranks to a jack-shaft, and thence to the driving-wheels. The overall length of the complete locomotive is 64 feet 11 inches, total and rigid wheel base of each semi-unit respectively 23 feet 1 inch and 7 feet 2 inches. The overall height is 14 feet 8⅛ inches, and extreme width 10 feet 8¼ inches. In running order the engine weighs 156½ tons, of which 99½ tons are distributed over the 42-inch driving-wheels, giving a weight of 79,750 lb. per driving-axle. The rated tractive effort is 66,000 lb., but in actual service this has been raised to 79,200 lb. Although designed to cope with a train weighing 550 tons, these electrics are often called upon to start upon the ruling grade with 850 tons, and have proved their capacity to haul trains composed of fourteen all-steel coaches, exceeding 1,000 tons, without difficulty. While the normal working speed is 44½ miles per hour, a speed of 80 miles an hour can be attained in perfect safety.



INTERNATIONAL GENERAL ELECTRIC FREIGHT LOCOMOTIVE FOR THE CHICAGO, MILWAUKEE AND ST PAUL RAILWAY.

Constructed in two duplicate half-units, it measures 112 feet in length, has 24 wheels—of which 16 are drivers—and weighs 288 tons.

The section upon which these electrics operate extends from Harrison upon the New Jersey side of the Hudson River, to the terminal station in New York City, and thence through the tunnel under the East River to the Sunnyside Yards on Long Island. The links beneath the two waterways are steel-tubes similar to those incidental to British tube railways, but, of course, of more imposing diameter. The greater part of the duty of these electric giants is the movement of the trains in and out of New York City; the connexion with the steam-operated main lines of the Pennsylvania Railroad is made at the point known as Manhattan Transfer. The scheduled allowance for engine change, including the necessary testing of the air-

brakes, is 4 minutes. In actual practice, however, the task is generally accomplished in 3 minutes, and upon occasions has been performed in 2 minutes.

These locomotives were first placed in regular service in 1910, and on November 8th, 1914, completed four years' constant service. The period was deemed adequate to formulate a decisive idea of their performance, and a comprehensive and somewhat impressive range of statistics was prepared.

During the forty-eight months the locomotives engaged in this duty—which involves a short run—covered 3,974,746 miles—the aggregate of 463,558 train movements. In the fulfilment of this mileage only 45 engine failures were recorded; the aggregate delay arising from such mishaps was 271 minutes, or an average of approximately six minutes for each failure. This is equivalent to a breakdown in every 88,328 miles covered—a striking tribute to the robust character of the design, and the perfection of construction.

88,000 miles with one Breakdown

As a result of the highly satisfactory work of these engines, examination has been reduced to a very simple process. Each locomotive is passed over an inspection pit once every 24 hours to permit a running investigation of the machinery and the carrying out of any slight repairs. This is a perfunctory task seeing that it only occupies about 10 minutes. At the end of each 3,000 miles run the locomotives are sent into the shops for a general examination, when all the electrical apparatus is thoroughly inspected, tested, cleaned, and, if necessary, adjusted or renewed.

Visits to the workshops for general repairs are governed by the necessities of tire-overhaul, and as in several instances the distance covered ranges from 90,000 to 112,000 miles before this necessity arises, it will be seen that the workshop visit is decidedly infrequent.

When the Chicago, Milwaukee, and St. Paul Railway embarked upon the electrification of the 440 miles of its main line through the Rocky Mountains it called for some exceptionally huge and powerful locomotives. The first fleet of 42 electrics was built by the International General Electric Company at their Schenectady workshops, and they are striking expressions of the electric locomotive builder's craft. Each locomotive is composed of two units, but in this instance each half is a self-contained power section in itself. It can be detached from its fellow and used alone, in accordance with the practice favoured for the movement of the local trains run over the electrified section.

These electrics measure 112 feet overall length, 10 feet in width, by 16 feet 8 inches in height from rim of wheel to the highest point of the pantograph collector when locked down on the roof in the closed, or off, position. Each unit comprises two trucks, the front dissymmetrical truck carrying the two bogie-axles mounted in a subsidiary bogie-truck, and two driving-axles, while the second and symmetrical truck also carries two driving-axles. The total wheel base is 102 feet 8 inches, rigid driving-wheel base 10 feet 6 inches, and rigid guiding-wheel base 6 feet.

As a result of this arrangement the locomotive has a 4-wheeled bogie-truck at each end with four sets of driving-wheels between, giving the locomotive the 24 wheels under the classification 4–4–4–4–4–4. The drivers are 52 inches in diameter while the truck-wheels have a diameter of 36 inches. The total weight of the locomotive ready for the road is 576,000 lb. —288 American tons—of which 450,000 lb. are distributed over the eight driving-axles giving 56,250 lb. per axle. The continuous and maximum tractive efforts are 71,000 and 132,500 lb. respectively.

An Articulated Giant

A length of 112 feet was imposed upon

the builders because of the enormous hauling capacity set down. This, in turn, demanded tremendous power, to supply which necessitated the mounting of eight motors. Articulation of the trucks ensures not only the easy negotiation of the sharp curves at high speeds, but reduces the wear upon the flanges of the tires to the minimum. It also assures simple and effective equalization of weight, gives excellent foundation for the brake system, and extends ideal support for the motors as well as facilitating their adequate ventilation. The springing is also carried out upon elaborate lines, while the leading bogie is so mounted as to permit the entering of the sharpest curves without disconcerting lateral lurching.

The cab is of the conventional box-type enclosing each unit and divided into two parts. The forward space constitutes the driving-cab, which measures 10 feet in width by 5 feet in length. Behind this is the compartment, 47 feet in length, housing the whole of the electric apparatus. This is disposed centrally along the longitudinal axis of the body, and flanked on each side by a gangway 23 inches wide to permit access to the machinery while running.

The eight motors are disposed in pairs, one pair to each truck, along the longitudinal axis of the locomotive. On either end of the armature of each motor is mounted a pinion which engages with a gear-wheel set up on either end of the driving-axle, the motor thus being twin-geared to its driving-axle. Flexibility and the reduction of all shocks set up by inequalities in the track, which might be transmitted through the gearing to the motors, are assured by the use of a spring-gear and a spring-nose suspension. This not only contributes the advantages already cited but also lessens gear wear.

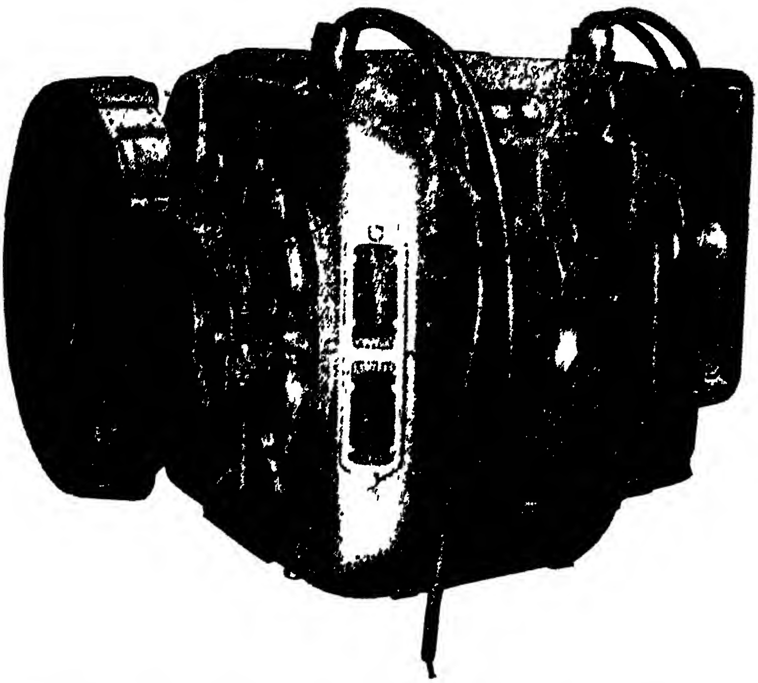
Each motor has a continuous rating of 375 horse-power and develops 450 horse-power under the one-hour rating; the complete power equipment for the whole locomotive is thus 3,000 horse-power under continuous, and 3,600 horse-power under the one-hour, rating respectively. The foregoing motor ratings are for a potential of 1,500 volts, but as this railway is operated at 3,000 volts, two motors are connected in series. An external blower is supplied for cooling purposes; the volume of air driven through the motor under continuous rating conditions, when the armature is making 446 revolutions per minute, amounts approximately to 2,500 cubic feet per minute. The total weight of the motor unit complete, including the spring gears, pinions, case and axle lining is 4,680 lb.

The locomotives designed for passenger and freight service are identical in design except for the gear ratio. Each of the pinions on the armatures of the motors of the first-named carry 29 teeth, while each axle-borne gear-wheel

RUNNING GEAR OF ONE-HALF UNIT OF THE INTERNATIONAL GENERAL ELECTRIC FREIGHT LOCOMOTIVE.

Showing dissymmetrical truck with four-wheeled guiding bogie and two driving-axles, and symmetrical truck with two driving-axles.

has an equipment of 71 teeth. This gear ratio permits the locomotive to haul a train weighing 800 tons at a speed of approximately 60 miles an hour on a stretch of level straight track. The weight of the average passenger train hauled through the Rocky Mountains ranges from 650 to 700 tons, and this is moved over the ruling grade of 1 in 50 by a single locomotive. For freight service the armature pinions are given 18 teeth meshing with gear-wheels of 82 teeth; this ratio permits the single locomotive to draw a trailing load of 2,500 tons over all banks up to, and including, 1 in 100, at a speed of 16 miles an hour. On the 1 in 50 inclines the locomotive load is reduced to 1,250 tons, but in practice this limit is freely exceeded.



375-HORSE-POWER MOTOR FOR THE INTERNATIONAL GENERAL ELECTRIC FREIGHT LOCOMOTIVE.

Eight of these motors are geared to the eight driving-axles, and give a maximum collective output of 3,600 horse-power.

The electric fleet of the Chicago, Milwaukee, and St. Paul Railway has been further increased by ten Baldwin-Westinghouse locomotives of greater power. They are shorter than the General Electric engines, measuring 88 feet 7 inches overall length, but they weigh 275 tons, and are more powerful, developing 3,200 horse-power under continuous rating and 4,000 horse-power under the one-hour rating. The wheel arrangement is also different; there are twelve drivers, 68 inches in diameter, disposed in two groups of six each, with a 4-wheel bogie-truck at each end, and two trailing or carrying axles in the centre. Reverting to the analogy of two steam locomotives coupled back to back, the result achieved is, in the present case, as if two "Pacifics" were connected in this manner, the classification being 4–6–2–2–6–4. Unlike the Pennsylvania tunnel locomotives, the box body is continuous from end to end, although the arrangement of the power generating components is broadly similar, in that it is carried immediately over the six driving-wheels concerned. Gear-drive, in this instance, is adopted in preference to the cranks and side rods.

The motors are of the Westinghouse twin-armature, geared type with quill-drive. This arrangement not only permits the most effective use of the space between the driving-wheels, but enables the voltage applied to the individual armature to be reduced to 750 volts. As two armatures are geared to the same quill, an output of 1,500 volts is obtained: while the permanent operation in series of four armatures assures that the designed working capacity of 3,000 volts—the pressure adopted upon this railway—is maintained. Three of these motors, each developing 700 horse-power,

THE MOST POWERFUL PASSENGER LOCOMOTIVE IN THE WORLD.

A 275-ton, 3,000-volt, direct-current, 4,200-horse-power electric locomotive, built by the Westinghouse Electric International Company for the electrified section of the Chicago, Milwaukee and St. Paul Railway through the Rocky Mountains.

are mounted upon each truck, or six for the complete locomotive.

The concentration of all the auxiliary and control apparatus in a single cab 78 feet in length by 11 feet in width, constitutes another noticeable feature, despite the fact that the power capacity is much in excess of the double-unit engines first placed in service. The later practice conforms with the present tendency towards the conservation of weight and space for a maximum output of power. The cab is carried on two main running gears, each having a 4-wheeled guiding truck, 3 driving-axles mounted in a rigid wheel-base measuring 16 feet 9 inches, and a 2-wheeled trailing truck. The main running centre-pins are set midway between the first and second driving-axles of each running gear. On the one the centre-pin is designed to restrain the cab both longitudinally and laterally, while on the other running gear the cab is restrained only in the lateral direction, thus giving relatively free longitudinal movement. Under this arrangement the cab is relieved of all pulling and bumping strains. Each driving-axle carries 56,000 lb., and the total weight available for adhesion is thus 448,000 lb.

Arrangement of the Cab

A further conspicuous point is the reduction of all high-tension apparatus in the cab to the minimum. Among the various and indispensable auxiliaries there is only one piece of high-tension apparatus. This is the small motor-generator employed for charging the storage battery installed for the lighting of the train. The whole of the other apparatus is low-voltage, which has brought about a simplification of the equipment and wiring, eliminated complications of installation, maintenance and operation, and banished the hazard incidental to ordinary inspection and the operation of all switches and accessories, which is by no means insignificant when power of 3,000 volts prevails in the cab.

Another characteristic refers to the marked flexibility of the running speeds. It bestows upon this locomotive practically the self-same advantages that are forthcoming from an automobile fitted with change-speed mechanism; the object is attained without rheostatic losses. It is an arrangement which is eminently adapted to locomotives engaged in passenger duty, conducing to the economical operation of the train. The control of the engine is fitted with what may be described as nine definite running positions; the range of speed obtained in this manner varies from 8 to 56 miles per hour according to the load. It is accomplished on the locomotive by an arrangement of the six 1,500-volt twin-motors for three-speed combinations comprising—Position I, one set of 6 motors in series; Position II, two sets of 3 motors in series; Position III, three sets of 2 motors in series. These combinations give one-third, two-thirds, and full speed. In changing from one speed combination to the other, tractive effort is maintained.

Each of these locomotives is endowed with adequate power to haul a train of twelve steel coaches over the entire mountain section between Harlowton and Avery at the same speed as the schedule demands for the train of lighter weight handled by the other electrics. The tractive effort at starting is 112,000 lb., and on the level tangent track a train of the above-mentioned weight can be hauled at approximately 56 miles an hour, while, on the banks of 1 in 50 the speed is about 25 miles an hour.

Italian Giants

Although in Europe, owing to the vast difference between the traffic and other conditions, the electric locomotive has not been advanced to such imposing proportions, either in regard to dimensions or power, as has been recorded upon the American continent, many notable types of this character have been built for varying

service. One of the first countries to turn to electricity for the operation of railways was Italy. This action was influenced by economic motives. The country possesses no fuel resources, either solid or liquid, but being richly endowed with water-power, it was only logical to turn this asset to advantage.

It was about twenty years ago that the first step in the electrification of the main lines was taken in hand. The initial moves were necessarily of an experimental character, since much remained to be learned concerning the precise significance of this factor. Among the lines first transformed were the Valtellina, 66 miles, the Giovi, 12·4, and the Mont Cenis tunnel, 7·59 miles in length, respectively. The three-phase system with a frequency of 15 to 16·7 per second was adopted, with the pressure in the conductor set down at 3,000 to 3,300 volts.

During the past few years the electric locomotive equipment of the State system has been enhanced by some notable types constructed for the main-line working of the express traffic. One contract, embracing eighteen locomotives, was placed with the Brown-Boveri Company, of Milan, which is allied with the well-known Swiss organization of the same name, and the Breda, and Miani and Silvestri engineering companies; the first-named was responsible for the whole of the electrical details, while the two latter shared the construction of the mechanical equipment.

Brown-Boveri Types

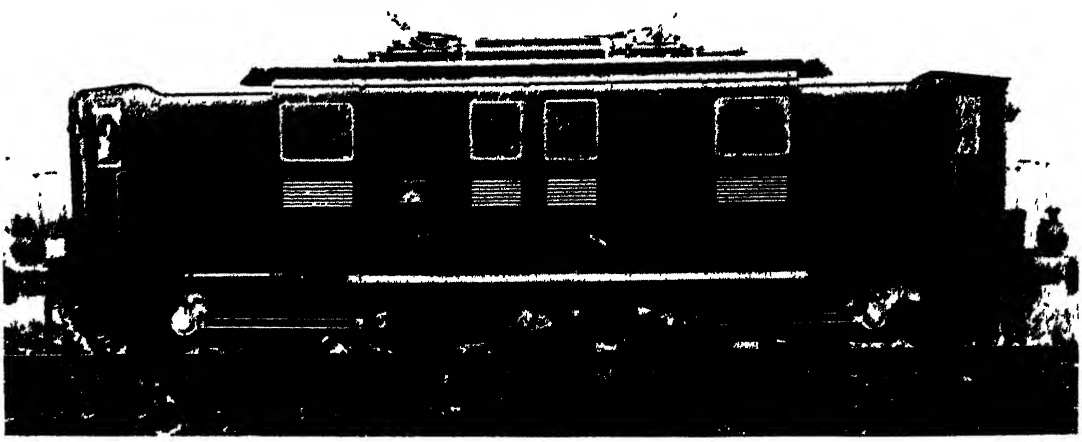
These locomotives have 14 wheels, the arrangement being 4–6–4. The carrying-axles are mounted in pairs in a bogie-truck at each end, while the three driving-axles are coupled. The overall length is about 45 feet; the total weight imposed is approximately 92 tons—50 tons are represented by the mechanical parts, and the electrical features are responsible for 42 tons. The distribution of the weight is 10·6 tons upon each carrying-axle, and 16·5 tons upon each driving-axle, so that the weight available for adhesion is 49·5 tons. The driving-wheels are 66 inches in diameter.

Each electric locomotive is fitted with two motors; the drive is transmitted to the axles through gearing and side rods, which registers a maximum starting effort of 26,400 lb. Four defined travelling speeds are provided—23½, 31¼, 47, and 62½ miles an hour respectively. On the assumption that 95 per cent. of the power developed by the motor is transmitted to the rims of the driving-wheels, it may be mentioned that, at the lowest speed, the tractive effort developed is 19,800 lb. with an output of 1,250 horse-power, and at this speed each motor gives at the shaft, on the hourly rating, 660 horse-power.

At the second speed the tractive effort remains unchanged, but the power delivered by the motors is 1,670 horse-power with 880 horse-power under the hourly rating for each motor. At the third speed the tractive effort is 20,900 lb. with a combined motor output of 2,640 horse-power and 1,390 horse-power per motor for the hourly rating; while, at the maximum speed, the tractive effort is 13,200 lb., a total output of 2,220 horse-power, and 1,170 horse-power for each motor under the hourly rating. These four definite speeds were purposely incorporated to meet varying conditions of traffic with economy, and to enable the electric to supersede the steam locomotives engaged in the express services with distinct advantage.

Advantages of Four Speeds

The highest speeds possible under the prevailing physical conditions of the track were imperative; similarly a speed of 62½ miles an hour was set down as the maximum permissible. The introduction of four definite speeds may probably lead to the assumption that the electrical equipment is complicated, but in reality this is not



AN ELECTRIC GIANT FOR THE ELECTRIFIED STATE RAILWAYS OF ITALY.

One of the latest and most powerful Brown-Boveri electric locomotives designed for express passenger service. It has six coupled driving-wheels, weighs 92 tons, develops 2,780 horse-power, and has a maximum speed of 62½ miles per hour.

so. The two lower speeds are obtained by running the motors in cascade, while the two higher speeds are secured by placing them in parallel.

One of the most prominent features of these locomotives is the extensive supply of compressed air, more particularly in connexion with the driving-controllers. In this respect these electric locomotives are even distinctive, because this agency has been pressed into service upon a larger scale than has ever been previously recorded, at least so far as European practice is concerned. The controller follows the accepted electrical lines in design, but it is actuated by compressed air instead of current, through an ingenious combination of cams, levers, air-conductors and valves. The purpose of the valves is to control the flow of air either to or from the specific mechanism connected therewith and the compressed-air reservoir, respectively, as well as its escape into the outer atmosphere, according to the character of the manipulation to be fulfilled. The controller may be said to be an exact counterpart of its familiar electrical contemporary, except that pipes take the place of wires, and valves supersede the contacts.

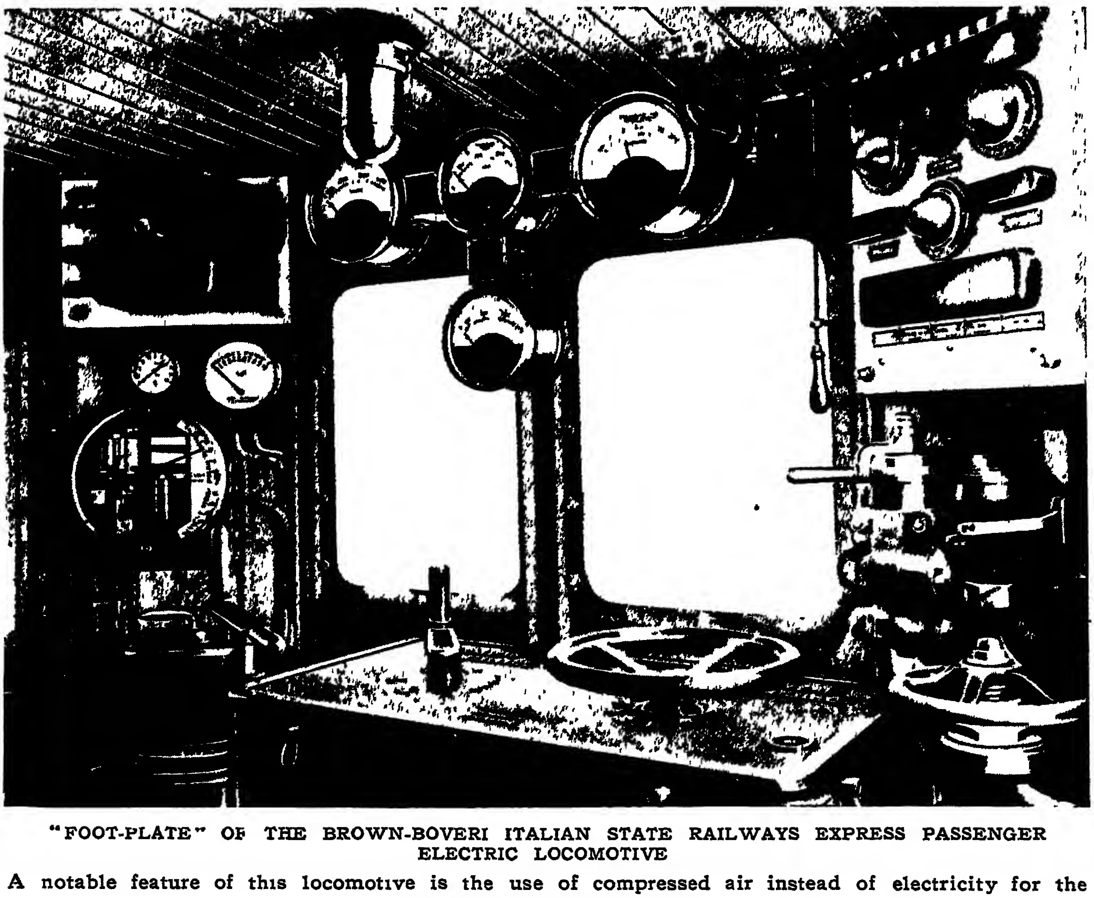
These locomotives have proved highly efficient in service, especially in regard to starting under load and acceleration. A train weighing 335 tons, exclusive of the locomotive — with locomotive the total weight is 427 tons—starting from rest upon a grade of 1 in 83, accelerates to the speed of 47 miles an hour in 250 seconds, or one-half of the period set down in the specifications imposed by the Italian authorities; while a train of 185 tons, exclusive of the engine, can start and notch the maximum speed of 62½ miles an hour upon a bank of 1 in 286 in 135 seconds. The results with double locomotive effort have proved equally satisfactory.

A goods train weighing 600 tons—784 tons with the two locomotives—and passenger trains weighing 374 tons, or 558

tons with the two locomotives, are easily hauled at the respective speeds of 31¼ and 62½ miles an hour.

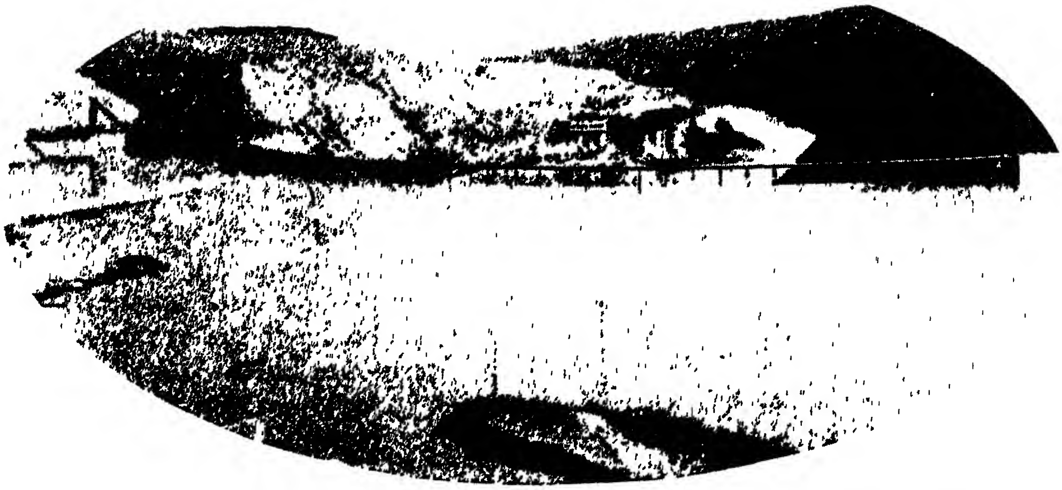
When two locomotives are employed the practice is to couple them to the two extremities of the train, but under separate control, although the driver of the rear engine has to follow the operations of the leader so that the efforts of the two engines may be identical. When the practice was introduced the two drivers maintained communication, in regard to the operation of the respective units, by a code of signals given by the whistles, but experience proved that the echoes, and the noise of the train when running, tended to render the signals somewhat confusing; at least they lacked that quality of distinctness essential to perfect response and accuracy in operation. Now reliance is reposed in the readings of the wattmeters installed in the two drivers' cabins.

In starting, to all intents and purposes, the movement of the levers in the two locomotives to the first speed-notch is effected simultaneously. From this point the leading driver acts as the pilot; the second driver is guided in his operations solely by the wattmeter. When the leading driver moves his control handle forward to the next speed-notch, the action causes the needle of the wattmeter in the rear locomotive cabin to move and to assume a lower position upon the dial. The rear driver immediately moves his lever forward to make the necessary connexions, thereby taking up his share of the load. After a little practice starting, accelerating, decelerating, and stopping can be carried out with complete facility.



"FOOT-PLATE" OF THE BROWN-BOVERI ITALIAN STATE RAILWAYS EXPRESS PASSENGER ELECTRIC LOCOMOTIVE

A notable feature of this locomotive is the use of compressed air instead of electricity for the operation of the controller.



THE GREAT FALLS LAKE, OR STORAGE RESERVOIR, ON THE MISSOURI RIVER
Looking downstream over the top of the dam 72 feet in height, showing, in the foreground, the impounded water, which gives a storage of 3,000 acre-feet; and beyond to the deep canyon through which the river flows.

Taming the Falls of the Missouri River—II

HOW A GREAT AMERICAN HYDRO-ELECTRIC ENTERPRISE WAS CONSOLIDATED

IN the year 1912, matters electrical in the State of Montana received a dramatic forward impulse. The railway company serving the copper combination, the Butte, Anaconda and Pacific, announced its intention to change over from steam to electric working. About 70 miles of main line and branches were to be electrified in one single step. Once railway electrification was begun and its efficiency and economy proved, there was no saying where the movement would stop, seeing that the state is well served with railways, and that three transcontinentals span its breadth. It was vitally important to consolidate the various electrical enterprises into a single homogeneous whole, so that continuity of power-supply to the limits prevailing under all and varying conditions might be guaranteed.

Amalgamation was a complex and somewhat formidable undertaking, but the moment being opportune, it made distinct appeal to Mr. John D. Ryan. As president of the Great Falls Power Company, his opinions carried immense weight. Consequently, when he announced that the various hydro-electric interests in the Great Falls territory should be welded into a single entity, he did not encounter that opposition which often attends proposals to unify various competitive undertakings.

He set out to acquire commanding interests in the various companies, and merged

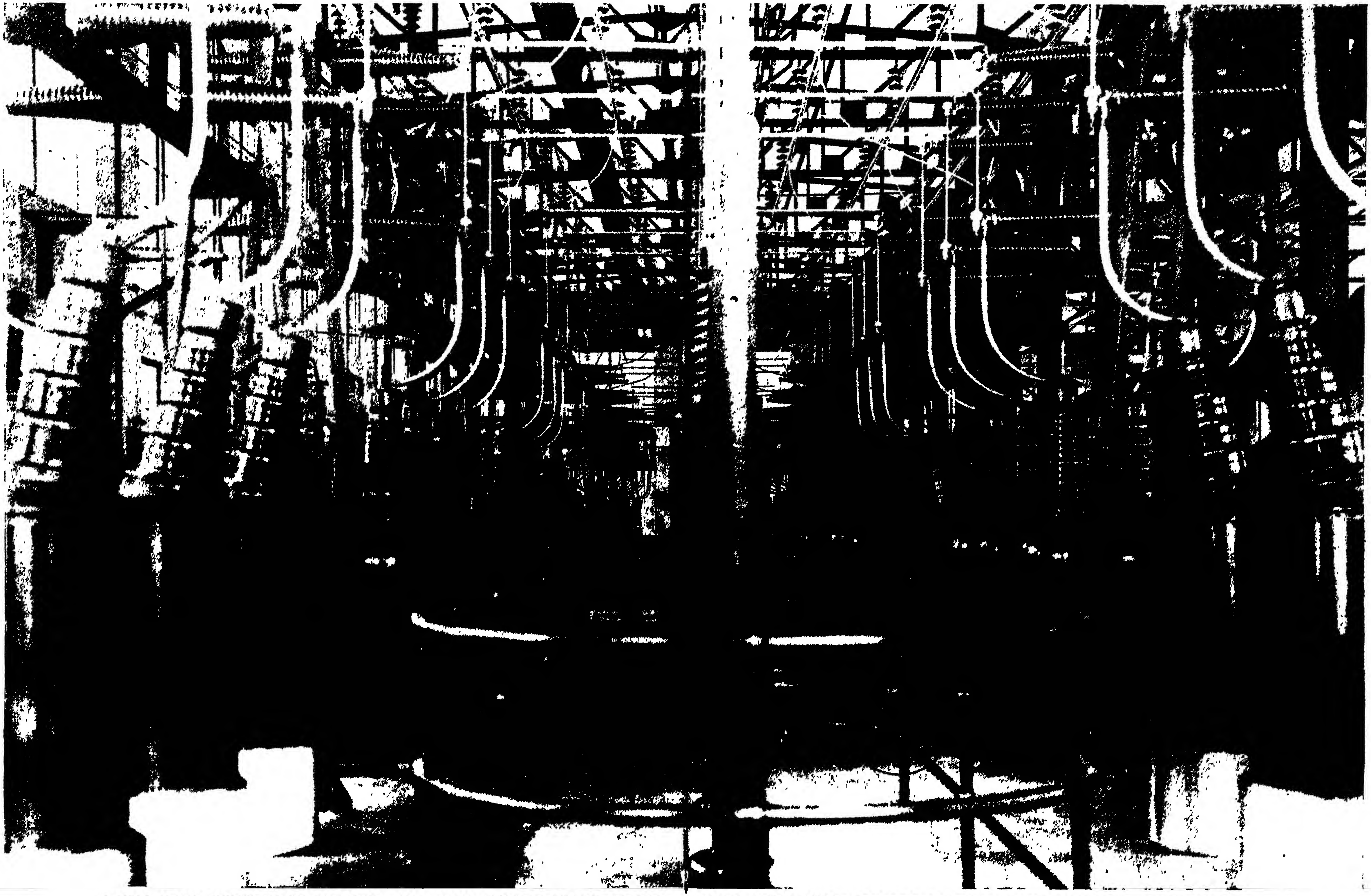
them into the one comprehensive enterprise now known as the Montana Power Company. Not only were the power generating installations already described brought under one control, but another big project, then in the embryo stage, which involved the harnessing of the Thompson Falls upon the Clark Fork of the Columbia River in the south-western corner of the state, was also secured.

Under Mr. Ryan's comprehensive scheme it would become possible to draw power from different stations according to the fluctuations in demands and conditions. The engineer, chemist, and scientist have achieved wellnigh incredible triumphs, but, so far as hydro-electric supply is concerned, they are impotent in the primary issue—they cannot control the rainfall. The natural replenishing action is conducted at varying times over different watersheds. Regulation of stream-flow by the creation of artificial lakes and storage reservoirs merely represents man's puny attempt to rectify the apparent omissions of Mother Nature.

Commerce and industry are not disposed to recognize any such subservience to an ultra power. Furthermore, Mr. Ryan realized that single control must lead to the reduction of costs and a greatly enhanced service, because a call could be imposed upon any or several stations to meet the demand for current in the event of supply from the nearest ostensible source suffering interruption or depreciation. Repairs

THE GREAT FALLS OF THE MISSOURI RIVER BEFORE THEY WERE HARNESSED BY THE MONTANA POWER COMPANY.

The natural drop of the river at this point is 78 feet. By throwing a barrage across the waterway above the cataract a working head of 150 feet has been obtained to generate 60,000 kilowatts.



WHERE 110,000 VOLTS REIGN SUPREME. THE HIGH-TENSION FLOOR OF THE GREAT FALLS HYDRO-ELECTRIC STATION OF THE MONTANA POWER COMPANY.

The current, after being led from the generators at 6,600 volts to the transformers to be stepped-up to 110,000 volts, is brought to this compartment which contains the wonderful massive oil-switches and lightning arresters, and is then conducted through the bewildering overhead network of bus-bars, supported upon imposing insulators, to the roof terminal of the express transmission system.

PIT LINER PLACED IN POSITION.

This section of the turbine equipment is set in the top of the scroll case, which is almost completely buried in solid concrete.

classes of service—light, heat and power.

Under the consolidated conditions the Montana Power Company was able to satisfy the administration of the Butte, Anaconda and Pacific Railway. Accordingly, the change-over was put in hand and was completed in 1913. As estimated, electrical operation showed a striking superiority over steam in working costs. The savings effected were proved by experience to be at least 50 per cent. in excess of the promises made by the engineers concerned; while within three years the tonnage was increased by over 50 per cent. Had steam operation been maintained, the railway engineers admitted that they would not have been in the position to handle this additional business without incurring considerable extra

would also be carried out under more favourable conditions; the consumers would not suffer rationing under an intimately interlocked system. Complete cessation of supply could not be recorded except under the simultaneous collapse of all the plants. This was too remote a contingency to be contemplated, although the failure of one or two at one and the same time might occur. Finally, owing to the peculiar economic conditions incidental to electrical energy, the more equitable distribution of the load to the advantage of each of the stations would be secured, and rates would be reduced to the advantage of the consumer. In the State of Montana, the rates for electricity, which are uniform to all customers in the same group, are fixed by the State Public Service Commission. Grading is according to the three

COMPLETING THE SCROLL CASE.

Showing the distinctive shape of the tubular channel enclosing the turbine, and the peculiar course the water must follow to play upon the water-wheel.

capital expenditure in the provision of further tracks.

The successful operation of the Butte, Anaconda and Pacific Railway was responsible for the launching of a far more ambitious electrification scheme by another company—the conversion of the 440 miles of the Chicago, Milwaukee and St. Paul Railway between Harlowton and Avery, the story of which we have already given on pp. 79 *et seq*. It is safe to assert that but for the existence of the Montana Power Company the electrification of this transcontinental railway would have remained unaccomplished to this day.

When, however, the railway engineers attacked the problem, their search for power was simple and straightforward. They had only to treat with one potential supply undertaking. Mr. Ryan assumed a formidable responsibility, but he was fortunate in having as his chief electrical engineer and general manager Mr. Max Hebgen, a technician as daring and imaginative as himself, and gifted with similar powers of organization. The railway administration was satisfied, and so the project was sanctioned.

While the railway engineers were busily engaged upon their preliminaries, the president of the Montana Power Company was hurrying forward his scheme to meet the heavy responsibility which he had shouldered. The supreme project was at last put in hand. This was the harnessing of the Great Falls of the Missouri. At the same time the Thompson Falls on the Clark Fork of the Columbia River were brought under control for the generation of electric energy essentially to meet the requirements of the railway.

The works at the Great Falls of the Missouri represented the most formidable essayed in connexion with the exploitation of the five cataracts at this point of the elbow described by the river. A massive concrete dam, 1,250 feet in length by 72 feet in height, was thrown from bank to bank in a graceful curve along the crest of the Falls, and this is crowned by a steel flashing system 14 feet in height. In this manner it became possible to obtain a working

A VERTICAL 12,000-HORSE-POWER TURBINE WHEEL ON RUNNER AND SHAFT.

The water plays upon the vanes, or blades, passing into the centre of the wheel to fall through the bottom into the draft tube, and thence into the tail-race. The generator is mounted upon the shaft so that it revolves with the turbine.

head of 150 feet of water with a storage of 3,000 acre-feet.

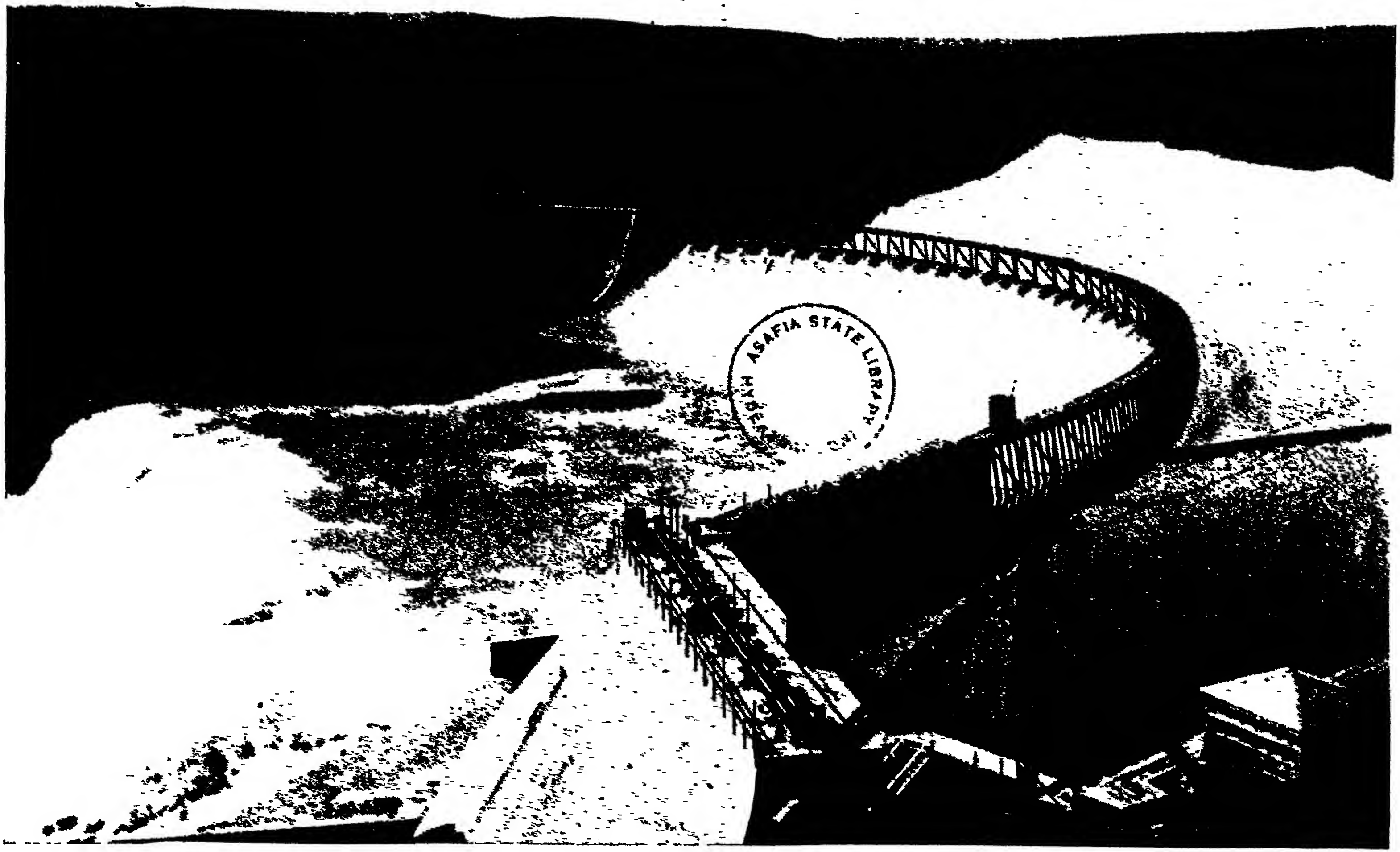
The forebay and power-house are on the northern bank. The peculiar character of the river channel immediately below the Falls, and its sudden constriction from about 1,100 feet above the drop to approximately 230 feet by the interposition of a tongue from the northern bank, rendered it necessary to excavate a tail-race, emptying into the river well below the Falls, for about 1,600 feet. The northern shore of

the bay into which the water drops was strengthened. The power-house, a handsome concrete and brick structure, is set at the foot of the dam immediately below the forebay. It is a three-floor building with basement, about 250 feet

TURNING HYDRAULIC INTO ELECTRICAL ENERGY.
One of the six 10,000-kilowatt generators installed in the Great Falls Power-house. Alongside is the wonderfully sensitive governor, by which the flow of water to the turbine is automatically controlled.

in length by 80 feet in height. From the forebay six pipe-lines or penstocks, 12 feet in diameter, buried in the concrete, carry the water to the six turbines placed in the basement of the building.

The generating plant is disposed in a single row and comprises six vertical-type single-runner water-wheel and generator units of 10,000 kilowatts each, generating power at 6,600 volts. On the second floor are four banks of transformers for stepping-up the current to 110,000 volts, together with auxiliary apparatus and switch-board. The third floor carries the high-tension switching apparatus and lightning arresters; while on the roof are mounted the terminal facilities for the six 110,000-volts transmission lines. The initial transmission equipment comprises three high-tension lines, two with a capacity of 15,000 kilowatts, running to Two Dot (to the west of Harlowton), a distance of 102 miles, to serve the Chicago, Milwaukee and St. Paul Railway. The third, of 30,000 kilowatts capacity and 143 miles in length, feeds the railroad system at Morel and Gold Creek near the centre of the 440 miles of the electrified section. This express line also serves the large smelting plant of the Anaconda Copper Mining Company, and is connected with the Rainbow system



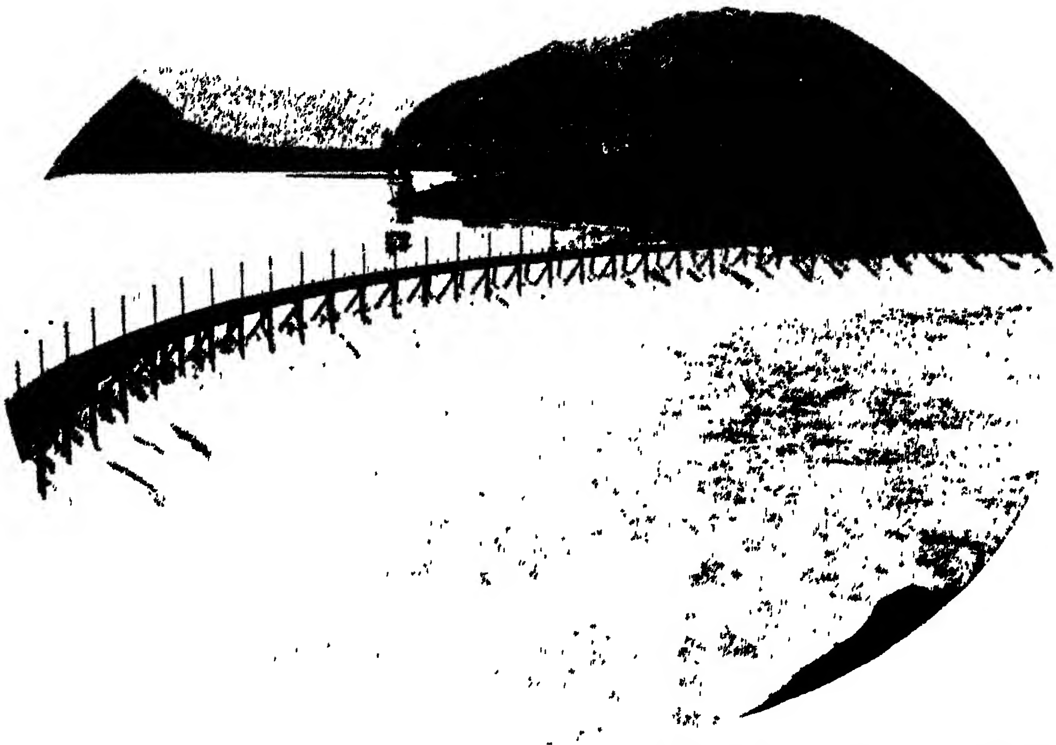
BIRD'S-EYE VIEW OF THE HARNESSING OF THE GREAT FALLS OF THE MISSOURI RIVER.

The barrage, built of concrete, 1,250 feet in length by 72 feet in height, is planted upon the crest of the cataract. The water is led from the lake through steel penstocks—buried in the concrete abutment in the foreground—to the turbines at the power-house, which is at the foot of the Falls.

by a high-tension bus-line about eight miles in length.

The Missouri River has its source upon the eastern slopes of the Continental Divide, and empties into the Atlantic Ocean. The Clark Fork of the Columbia rises on the western slopes of the mountain backbone of the continent, and so makes its way to the Pacific. The junction with the great waterway is made at Ft. Shepherd, in British Columbia. At the point selected for the erection of the generating station the river drops 15 feet, forming the Thompson Falls, but, owing to the ragged character of the channel and the fact that it is studded with islands, as well as that it has carved a flood channel which is dry for many months of the year, extensive development was entailed.

The principal work comprised a massive concrete dam of the gravity type, 1,000 feet in length by 35 feet in height, placed above the falls, and a subsidiary dam, 290 feet in length across the high- or flood-water channel, with waste gates at the western end. The configuration of the main river channel in the vicinity of the flood channel forms a natural forebay, and from this a canal, 600 feet in length, was cut through the solid rock to lead the water to the power-house placed beside the river about half a mile below the main dam. The station, a three-floor building some 300 feet in length, follows the usual



THE 1,000-FEET BARRAGE ACROSS THE CLARK FORK OF THE COLUMBIA RIVER AT THOMPSON FALLS.

To provide current for the operation of the western section of the Rocky Mountains electrified zone of the Chicago, Milwaukee and St. Paul Railway, for which energy derived from the Missouri River could not be used, the Montana Power Company harnessed this cataract. Practically the whole of the available 30,000 kilowatts is absorbed by the railway. The crest of the dam, it will be observed, is electrically lighted.

American practice in regard to its lay-out and disposition of equipment. It houses six vertical-type water-wheel units and generators, each of 5,000 kilowatts, the natural fall of the water, plus the dam, giving a total working head of 150 feet.

The power, generated at 6,600 volts and stepped-up to 110,000 volts, is transmitted over four lines, although provision is made for six high-tension outgoing lines. Two of these lines, about 21 miles in length, feed power to the Cœur d'Alene mining district on the Idaho-Montana border; the other two lines enter into the feed system for the Chicago, Milwaukee and St. Paul Railway at the extreme end of its western electric section. The latter are carried to East Portal on the interstate border, 25 miles east of the present western terminus of the electrified zone at Avery, Idaho.

This power-station is not linked up with the general interconnecting transmission system of the Montana Power Company at present, except by means of the 100,000-volt bus-line which the railway was compelled to build parallel with its own track and upon its right of way for 440 miles.

Feeding the Railway with Power

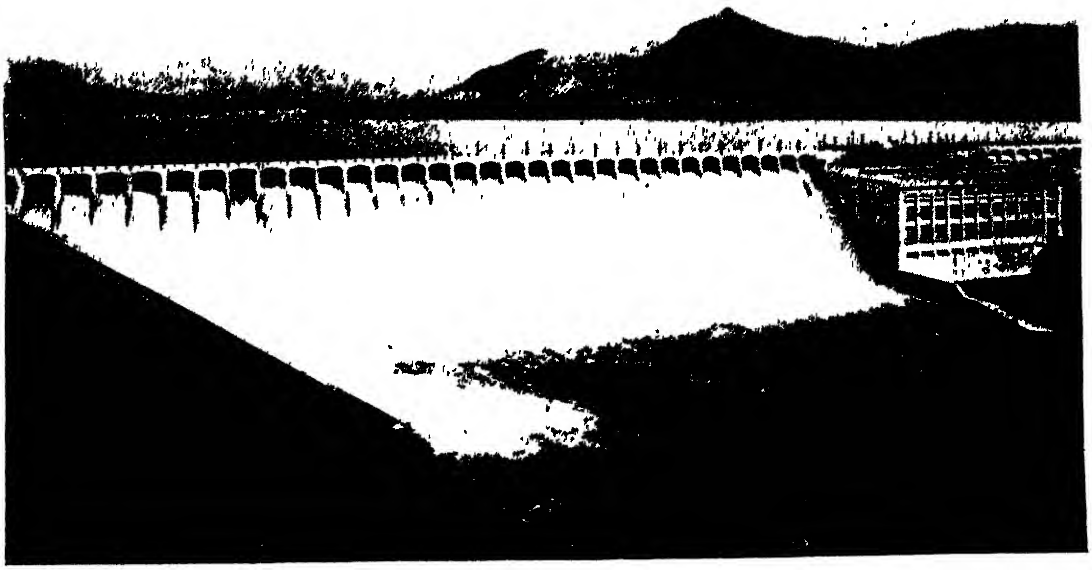
The Montana Power Company feeds this bus-line with power at 100,000 volts at seven intermediate points. This power is taken by the railway company's fourteen sub-stations, spaced at intervals of about 30 miles, to be broken down to the 3,000-volts pressure at which it is fed to the overhead conductor. This arrangement brings the railway service into electric-energy touch with at least two, and in some places three, sources of power at each sub-station. A breakdown in any section through the failure of the two or three power-stations immediately concerned is averted, because in such an event the load is taken up by other stations, owing to the perfect interlocking of the company's system. Should the isolated Thompson Falls power-station be thrown out of action, the western section of the electrified zone is not imperilled because power can be fed into the railway system at Gold Creek, the most westerly outpost of the distributing system for the railway in touch with all the other generating stations.

An Electrical Success

The urgent necessity for sufficient power to be furnished continuously to the railway is obvious from the fact that the almost uniformly maintained traffic is moving over the system the round twenty-four hours. During the year the railway load averages about 70,000,000 kilowatt-hours; the maximum monthly load is about 6,500,000 kilowatt-hours, and the minimum approximately 5,750,000 kilowatt-hours—a variation of about 12 per cent. When this undertaking was commenced, apprehensions were entertained by the railway company concerning continuity of the service relative to the effect of the supposed fluctuating load a railway would impose. Experience has proved that all the uncertainties which reigned were unfounded. Railway electrification, if efficiently organized, represents one of the most satisfactory applications of electricity.

To secure the reserve supply of power which the Montana company considered necessary, it embarked in 1915 upon another big generating enterprise upon the Missouri River. The cataracts of the waterway having been harnessed, it now became incumbent to create a fall, or head of water. Survey of the sites along the river led to the decision that at Holter, 30 miles north of Helena, and near the centre of the power company's whole system, was a favourable site for the new project. At this point the river is wide, flowing between high-lying banks, with very low benches fringing either side, which are subject to inundation in times of high flood.

Here the company was confronted with an imposing engineering undertaking which represents the second largest installation upon the whole of its system. A heavy concrete dam, 1,350 feet long, with a uniform height of 100 feet, was built across the river. A prominent feature of the Holter project is its compactness. The power-house is built into the dam upon the down-stream side; only short lengths of conduits are required to conduct the water from the lake to the turbines. The building carries

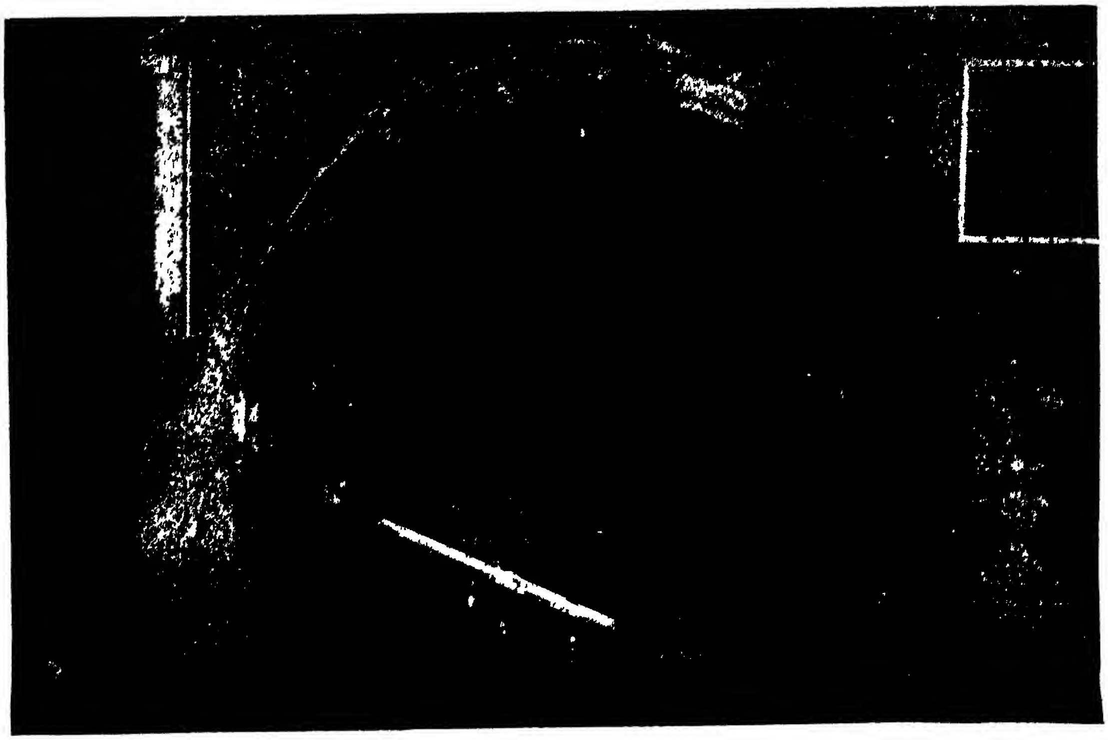


THE HOLTER DAM AND POWER-HOUSE.

Having harnessed the natural falls upon the river, the engineers of the Montana Power Company were compelled to rely upon the head of water—100 feet—produced by throwing a dam across the waterway. The whole of the available artificial fall in the water is turned to account to generate 40,000 kilowatts.

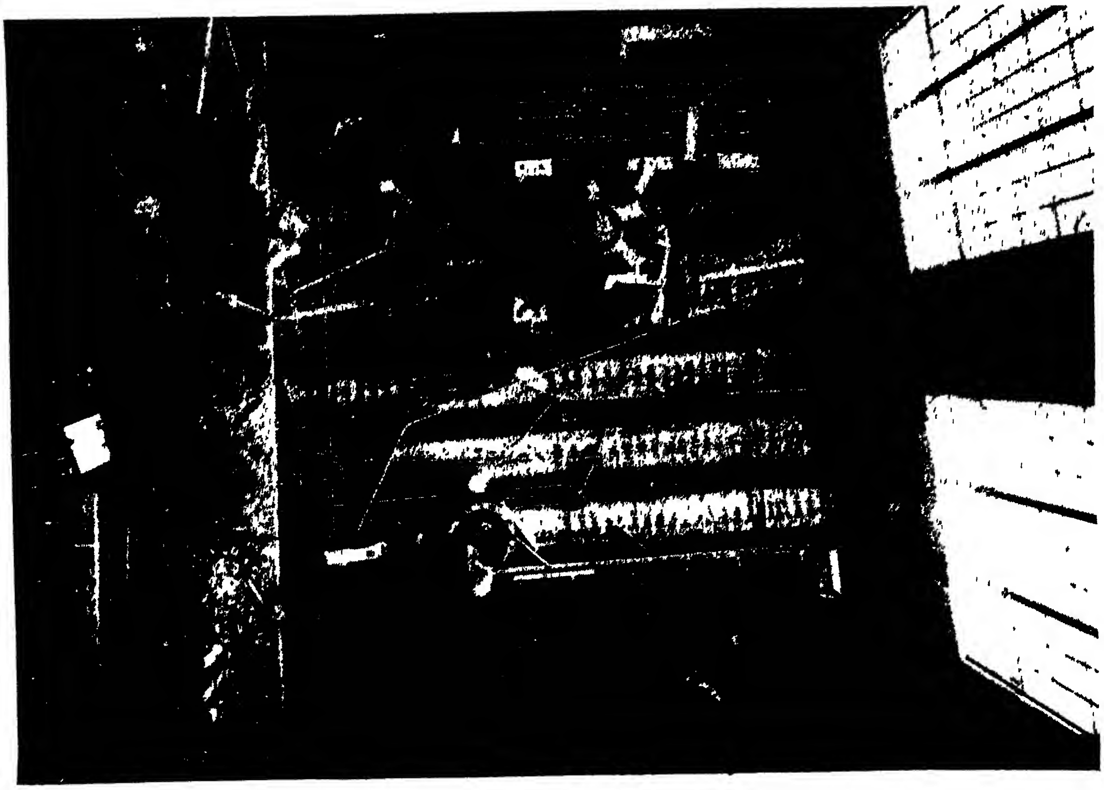
The whole of this head of water is utilized. The barrage is the highest built for any of the Montana hydro-electric schemes; the reservoir, which is formed by backing the water up the river, provides a storage of 50,000 acre-feet. This constitutes the second largest reservoir controlled by the power company, and, in conjunction with the Hauser Lake and Canyon Ferry reservoirs, converts the Missouri River into a chain of lakes over a distance of about 50 miles. The total storage thus made available for stream regulation on the lower Missouri at Great Falls amounts to nearly 150,000 acre-feet.

four vertical single-runner turbine units each of 10,000 kilowatts—a total output of 40,000 kilowatts. The power is transformed to 110,000 volts and delivered into the transmission line running from the Great Falls station to Morel and Anaconda, which crosses the river at this point. By the inauguration of the Holter hydro-electric undertaking the aggregate output of the thirteen installations of this character was lifted to 211,530 kilowatts. In addition to the foregoing there are four small steam-plants, at Butte, Billings, Conrad, and Phœnix (Butte) respectively, totalling 5,920 kilowatts. The largest steam-plant



LOOKING DOWN A WHEEL-PIT.

A novel photograph showing the depth of the shaft in which the turbine wheel is set. The top ring is flush with the floor of the generator room.



WHAT THE EYE DOES NOT SEE.

The floor of a generator room is impressively clear, but beneath the surface is a maze of conduits carrying the main cables from the generators. The projecting white stumps in this photograph of the Holter plant, taken during construction, are the entrances to the conduits for the cables leading from the 10,000-kilowatt generators.

(at Butte) is of 5,000 kilowatts, and is regarded as a reserve or stand-by station essentially to meet the public-service demands of the city.

While the foregoing various undertakings were being prosecuted, Mr. Max Hebgen was nursing a bold scheme for an immense storage reservoir at the head-waters of the Missouri River. The consolidation of the various generating and distributing companies enabled this project to be carried out. It is named after its designer.

The Hebgen Reservoir has been installed in a favourable depression near the source of the Madison River, a short distance west of the Yellowstone National Park, in which the Madison rises near the borders of Wyoming and Idaho. It comprises an earth dam with a concrete core, 718 feet in length by 87½ feet in height, with flood-water sluices and pipe-lines for control of the water discharge. A huge storage reservoir of 325,000 acre-feet has been formed to hold the flood-water which previously was lost and which, with an aggregate head of 600 feet, can now be used successively through six plants. The foregoing storage is increased by an additional 180,000 acre-feet represented by the various local development works and plants along the river to Great Falls. By the provision of the Hebgen Reservoir an adequate flow of water during the spells of extremely cold weather is assured. Moreover, as a result of the extensive work completed, the minimum capacity of the whole Missouri River hydro-electric generating system, as determined by normal low water, is increased by 87 per cent., and sufficient storage is provided to develop 100,000 kilowatts for one hundred days of the year.

Photo By courtesy of Montana Power Company

MAN AND THE MACHINE.

The switch-board in one of the large hydro-electric stations of the Montana Power Company, showing, in centre, the desk with its "mimic switch-board," whereby the "dispatcher" has complete control over all the complex hydraulic and electrical details throughout the station.

Although the enterprise of the power company has secured the output of 217,450 kilowatts almost entirely from the scientific control of rivers, so insistent is the demand for electric energy that further sites have had to be surveyed and secured for the generation of an additional 121,500 kilowatts. Of this total all but 7,000 kilo-

watts will be supplied from five new stations. The exception in question is due to the decision to reconstruct the station at Black Eagle Falls, thereby increasing its capacity to 10,000 kilowatts. Of the 13,500 kilowatts is to be planted at Fish Creek on the Missoula River. This will be coupled up with the Thompson Falls transmission system. The last project in this new programme carries the operations of

BEHIND THE BRAIN OF A HYDRO-ELECTRIC GENERATING STATION.

The switch-board of the Holter station of the Montana Power Company under erection, showing convergence of all the main cables from the generators, and the network of other wires which distribute electricity for power, light, heat and for the telephone service throughout the plant.

new enterprises the two largest will be above the Great Falls on the Missouri River, where a station of 28,500 kilowatts is to be built, and another of identical capacity on Sheep Creek below the Great Falls. The next in point of importance will be a third station upon the Madison River, giving 20,000 kilowatts, so that the total toll of electric energy drawn from the Missouri River between the Hebgen Reservoir and the point below the Great Falls, so far as at present contemplated, will aggregate no less than 262,500 kilowatts delivered from ten hydro-electric stations. Another important station of the Montana Power Company outside the boundaries of the home-state, because it involves the harnessing of the Snake River, Idaho. The site of the station, which is to be of 22,500 kilowatts capacity, lies a few miles west of the south-western corner of the Yellowstone Park.

From these extensive generating and distributing operations, an elaborate transmission system has been created, the outstanding features of which have been related elsewhere (*see* pp. 49 *et seq.*).

The following figures may prove interesting. Building the dams impounding sufficient water to actuate the round 50 turbines

installed in the thirteen stations, together with electrical equipment and transmission lines, involved an expenditure of £7,400,000. The company has control over 433,000 horse-power, representing swiftly rushing water, which for centuries was permitted to run to waste, and of which 283,000 horse-power has already been brought under subjection. This appears to be an immense volume of hydraulic energy, especially when so scattered, to be under the control of a single company; but when compared with the aggregate water-power running freely through the state to the oceans on either hand—which, according to official surveys, is estimated to be 2,750,000 horse-power at least—it represents but a drop in the proverbial bucket. At all events, there is 84 per cent. of similar potential energy awaiting exploitation in the service of commerce so soon as the demand arises.

During the year the total delivery of power exceeds 1,100,000,000 kilowatt-hours, for which the company receives about £1,370,000, and out of which it contributes over £150,000 to the State and Federal exchequers in the form of taxes.

THE WATER'S LAST RUN.

Setting the steel penstocks which conduct the water from the forebay of the lake above to the turbines installed in the power-house below. After the pipes have been tested they are buried in concrete.

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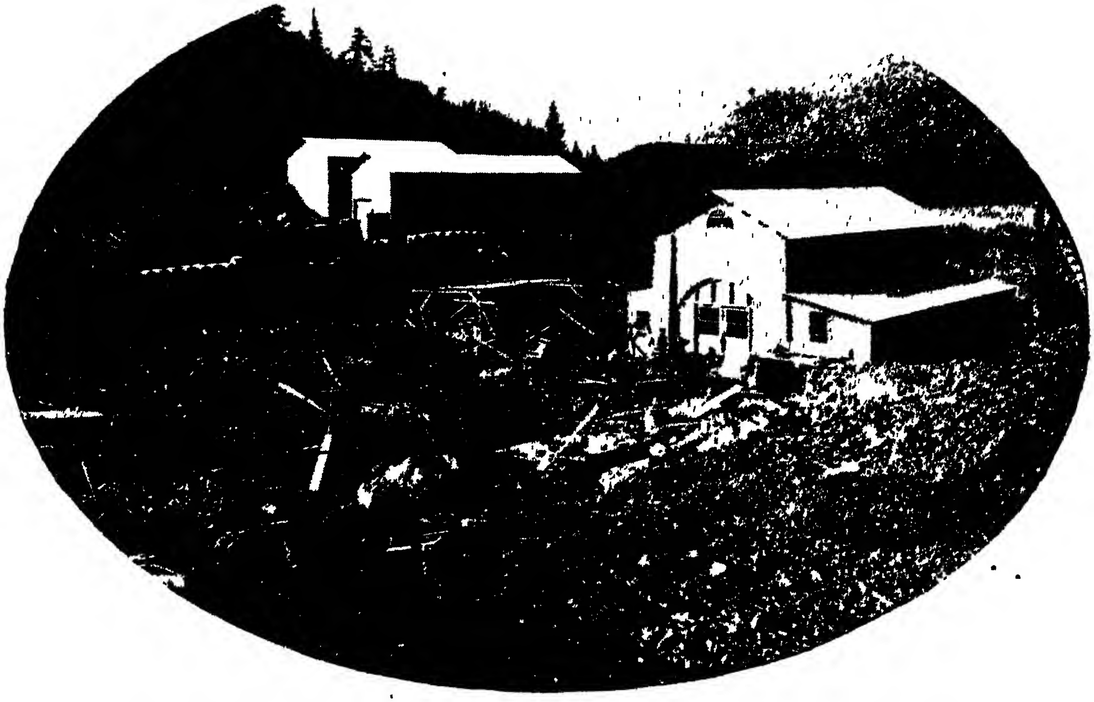

THE POWER-HOUSE TERMINAL OF THE "NORTH MOUNTAIN POWER LINE"
The plant of 2,000 horse-power under construction at Canyon Creek, whence runs to Eureka, upon the north Californian coast, one of the world's most remarkable "express transmissions."

Triumphs of Transmission—III

HOW BEE-LINE ROUTES HAVE BEEN CUT THROUGH DENSE FORESTS, ALONG PRECIPICES, ACROSS WIDE RIVERS, AND OVER YAWNING CANYONS

UNLIKE his colleague identified with the reconnoitring of a route for a high road or a railway through a new country, the engineer bent upon the plotting of a path for the transmission line is not trammelled with restrictions in regard to grade and curvature. He is concerned rather with the way of the eagle, so that he may spin his line as evenly as possible between its two extremities. A straight line not only saves valuable copper, but simplifies and cheapens maintenance by the mitigation, if not complete elimination, of severe side strains upon the poles.

Spying out the route is a task of peculiar fascination and adventure. One must necessarily work alone far from the beaten track, and often be solely dependent for direction upon the compass. Such a task involves the scaling of beetling crests, the penetration of dense forests, the threading of yawning ravines, wild scrambling over ragged, torn humps, dodging rolling boulders, and last, but by no means least, a ding-dong battle against the elements.

North Mountain Power Line

The plotting and building of some of the early long-distance transmission lines provided the engineers with all the thrills they could possibly have desired. The old North Mountain Power transmission line is an interesting case in point. This traverses a particularly wild and uninviting stretch of northern California, where the mountain ranges are exceptionally tumbled, and where the going is, or was, inordinately hard. In 1904 the company responsible for this enterprise entered into a contract to deliver electricity to Eureka from a 2,000-horse-power station, planted at the mouth of Canyon Creek on the Trinity River, by the first day of the following year. This plan was pursued owing to the summer drying-up proclivities of the streams upon the coast-line ranges. To obtain the essential constancy of water it was ne essary to drive back to the higher mountains.

The generation of the current at Junction City was simple; its delivery to Eureka was quite another matter. As the crow flies the distance between the generating and consuming centres is only 58 miles, but the route is about as difficult as one could conceive. Eureka lies at sea-level; Canyon Creek is 1,480 feet nearer the clouds; between are three straggling mountain ranges rearing from 4,500 to 5,500 feet.

The responsibility for the planning and construction of the transmission line between these two terminals was entrusted to Mr. H. L. Jackmann, the present manager of the Western States Gas and Electric Company, by which the original North Mountain Power interests were acquired. Mr. Jackmann reached Eureka on June 16th, 1904, when work upon the power-station had been commenced. The engineer-in-charge handed over the whole of the undertaking, because it did not lie within his sphere of activity.

Time was pressing. Mr. Jackmann decided to complete the plotting-out of the transmission line without further delay. He ascertained that a man, who knew the country thoroughly, had already been engaged to blaze a trail from Eureka to the Mouth of Canyon Creek on the Trinity River about 65 miles due east. This preliminary was imperative because the country was absolutely trackless, heavily timbered, and only settled here and there by adventurous squatters and ranchers, who had forced their way into the belt in the desire to be on the "ground floor." From this meagre information Mr. Jackmann concluded that he would be able to conduct his movements through the day in such a manner as to enable him to take advantage of the scattered ranchers' shacks for shelter at night.

"Blazing the Trail"

The engineer set out on the morning of June 17th with the object of finding his guide. After some twenty miles, he ran his quarry to earth at Maple Creek. Before the roaring camp-fire, the two discussed their plans. As the engineer had covered a third of the distance, he concluded that he would be able to complete the remaining 45 miles in record time. He rolled into his blankets determined to be up with the dawn fit for a hard day's ride, because directly ahead lay Snow Camp Mountain, over which they had to make their way.

In the morning one of the heavy, soggy, and marrow-freezing fogs peculiar to the North Pacific Coast had settled down upon the countryside, blotting out the landscape, drenching the thick tangled scrub, and threatening to render progress extremely difficult and uncomfortable. But the engineer nursed no apprehensions; he was in the hands of a trustworthy guide who could not possibly be baulked by even a "Pacific particular."

The two men hit the trail, but they had not penetrated far into the depths of the fog-enshrouded timber Avernus when

the surveyor grew uneasy. His guide was floundering about somewhat strangely and hesitatingly. At last, the engineer challenged the pilot as to whether they were on the right track. The man confessed that he had not the faintest idea where they were. The surveyor not only doubted whether the man had really blazed the trail to Canyon Creek, but even if he knew his way to that point. Still, having been swallowed up by the fog, it was useless to stand still or even to attempt retreat. There was also the faint hope that they might encounter a " hiker " or a ranch, and thereby be put on the trail. They drove ahead in silence, never easing their pace until nine o'clock in the evening, when they observed a light flickering through the fog. They hurried forward; the light gave way to the blurred outlines of a building. Imagine the disgust of the surveyor when he found that this was Bald Mountain House, a resting place only a few miles from Eureka. The two men had described a complete circle as the result of some sixteen hours of hard tramping and riding.

The surveyor returned to Eureka with the firm resolve that this, his first experience with a local pilot, should certainly be the last. He decided to obtain the services of a more reliable servant—a compass—and elected to complete the journey unaccompanied. Mounted upon a fresh horse Mr. Jackmann struck a compass course due east, so that he might reach by nightfall the home of a family named Bohall on the South Fork of the Trinity River. The engineer again plunged into the forest, but, discovering that his compass-course was taking him over the top of two lofty mountains which he wished to avoid, he bore to the south over the ragged country, and took his bearings at prominent points.

The day's ride was hard and long; when at last he struck a water-course known as Grouse Creek, he decided to follow it to its junction with the South Fork of the Trinity River, and thus gain the Bohall homestead. Daylight was rapidly waning when he gained the confluence of the waters to look round searchingly for the friendly ranch. It was nowhere to be seen, and no sound of human habitation floated through the silent forest. It was an unfortunate *impasse*. He could scarcely see a yard before him between the gloomy trees. To permit rapid travel he had set out with only sufficient food to carry him through the day. He could not even light a fire owing to the saturated condition of the wood. Although it was midsummer, the fog and the primeval forest shutting out the sun's warmth rendered the shade of the trees as cold as an ice-well. Dead-beat

BUILDING THE FIRST NORTH MOUNTAIN POWER LINE IN 1904.

A wide clearing had to be driven through the densely-timbered mountain country, down the centre of which a single wood-pole line was built. Sixty miles in length, this line is considered to be a masterpiece of transmission plotting, because at no point does it deviate more than two miles from the air-line.

though he was, he dared not lie down for cold, so he walked round and round a big tree throughout the night to keep himself from freezing.

At dawn he rambled up the river,

THE WAY OF THE NORTH MOUNTAIN LINE

The line climbs the mountain to an elevation of about 4,500 feet, traverses some 20 miles of saw-tooth country, and passes through the saddle of the high range in the distance.

hoping desperately that he was making towards and not away from the Bohall ranch. His pace was slow because of his fatigue, but after some two hours rambling he caught the sound of voices, and broke out of his timber prison into a clearing. This was the homestead which, as he presently learned, he had missed the previous evening by five miles.

The hospitable squatter gave him a hearty meal, but had to deny the engineer a most-needed sleep owing to lack of accommodation. But the solid meal had given Mr. Jackmann fresh life, and so he again struck his way east, stimulated by the surety of a night's shelter at Patterson's ranch-house on the farther side of the mountains, which Bohall said he would find if he held to his course.

Shortly after noon he breasted the top of the ragged ridge, and his eyes alighted upon the gleaming roof of a shack buried among the trees beneath him. He set a bee-line for this welcome object, which proved to be the Patterson home. Here he received a royal welcome, and a solid night's rest. The honest rancher gave him explicit directions concerning the road ahead to the settlement known as Junction City, which was gained without further incident.

Speedily satisfying himself as to the rate of progress upon the construction of the power-house, Mr. Jackmann set out upon his return to Eureka, and by avoiding part of his eastward route he was able to straighten the line he had plotted. By the time he regained Eureka he had almost completed his plans for the guidance of the constructional forces. While this part of the scheme was materializing, the organization of the survey and clearing parties was hurried forward. This task involved the cutting and clearing of the trees over a strip about 400 feet in width for 65 miles, up-hill and down-dale, to receive the line.

By the first day of July he had three survey parties and two clearing gangs in the field; as the surveyors advanced, three more gangs were added. Each clearing gang numbered from 30 to 100 men, and, relatively, the feeding and tending of such a large force proved to be the most difficult part of the work owing to the rugged character of the country. After negotiating one mountain ridge there is a continuous stretch of saw-tooth country

to the following ridge. Many of the peaks rise to 4,500 feet; while they are separated by precipitous canyons from 1,000 to 2,000 feet in depth.

Clearing in such a country, where the climatic conditions are favourable to dense big-timber growth, is exacting toil. A wide swathe must be driven to render the line immune from possible damage from trees levelled by wind, snow and rock-slides. The trees put up a stern resistance; the toll levied upon brawn, muscle, and keen-edged tools was heavy. White pine, spruce and redwood had to be brought down in profusion. The last named, for the most part, measured 4 feet in thickness at the stump, but there were frequent encounters with giants of 12 feet in diameter. They were not only troublesome to bring down, but infinitely more perplexing to demolish. A wooden pole-line was selected, and the felled trees afforded ample material.

POLE-SETTING GANG AT WORK UPON THE NORTH MOUNTAIN POWER LINE IN 1904.

This picture conveys a graphic idea of the rugged country and the heavy timber encountered. The right of way may be followed in the distance. In the course of 65 miles the line crosses three mountain ridges, running from 4,500 to 5,500 feet in altitude, and spans canyons from 1,000 to 2,000 feet deep.

The maintenance of the men in the field was conducted along somewhat unusual lines. The engineer did not attempt to drive even the usual temporary roadway through the country, because it would have taken too much time. He contented himself with a narrow, roughly driven pack-trail which merely followed the contour of the land, and to this day this is the only highway. Over this frail communicating link pack-trains of mules and horses moved unceasingly. One section of 45 miles was particularly difficult, and to ensure the men receiving adequate commissariat it was divided into eastern and western divisions respectively, with a base for each section of about 20 miles. The eastern depot was established 5 miles west of the power-house

on Canyon Creek; the western base was on Maple Creek 20 miles out of Eureka. The pack-trail was driven slightly in advance of the clearing parties until they finally met in the centre. Camps complete with the usual cooking equipment were not adopted, owing to the difficulties of moving the stoves. The men advanced with their sleeping tents, while the food, prepared and ready for immediate consumption, was sent up regularly by the pack-trains from the nearest kitchens.

Subduing the Mountain Barrier

In carrying through this transmission line, the time factor was an inexorable driving force. Each day there was a spirited fight against crashing timber, massive loose boulders and treacherous slides of loose detritus, which cascaded down the steep slopes with a deafening din. The scarred nature of the mountain flanks was yet another handicap. The huge canyons were supplemented by several deep, narrow fissures. The workmen promptly spanned the latter by dropping the big trees across them, then slashing back the branches to leave the bared trunks in the form of a crude bridge. But to pass from one wall to the other of the canyons was a feat of quite a different character. The general practice was to throw a wire cable across the gap, and to travel in large baskets slung from the aerial support. Both men and material were passed to and fro, and, when the necessity arose, mules were moved from one side to the other by a simple yet highly effective method. A sling was passed round the animal's body; the mule was then smartly whisked into the air to be whirled across the gorge with legs kicking freely until *terra firma* was regained. Notwithstanding the primitive method of transport, the mules appeared to become reconciled to the ordeal; at all events no untoward incidents were recorded.

This transmission is generally accepted as being one of the most notable ever completed, and Mr. Jackmann, its plotter, had the satisfaction of mapping out a path from Eureka to Canyon Ferry whereon the lateral deviation of route never exceeds two miles. Bearing in mind the abnormal topographical conditions, the engineer, by crowding on every available man, and speeding-up work to its limit against the advance of autumn rains and winter snows, achieved a great feat when he succeeded in getting current into the line on December 29th—two days before delivery was due. The transmission was reconnoitred, plotted and built for 65 miles in less than six months.

Unfortunately the engineer was debarred from scoring a complete triumph in his race against the calendar. Although current was got through by the date specified, the power-house was not completed. Two flumes on the hydraulic supply developed such faults as to demand replacement by a tunnel; but by June, 1905, the station was supplying energy to the limit of its capacity.

Disadvantages of Native Timber

Even to-day, despite the remarkable strides made in the science of transmission, the old North Mountain line provokes widespread interest, while its maintenance presents some pretty posers. The original line was carried on single 30-foot poles, with a 4-foot cross-arm and triangular construction. All went exceedingly well for about three years, and then pole trouble began to assert itself. The wet climate, and the fact that the posts were of native timber, precipitated rotting at the stumps. The poles commenced to totter. The line was repeatedly stubbed at intervals of about three years, but in actual fact the trouble-men were always engaged in this work at one point or another. It is not surprising, therefore, to learn that the upkeep of the line proved somewhat expensive.

In 1917, owing to the demand for power

HYDRO-ELECTRIC ACTIVITY AT SHAWINIGAN FALLS.

Although express transmission lines carry current in bulk to Montreal, Quebec City and to distant points south of the St. Lawrence, an appreciable volume is consumed locally by various electro-chemical industries, including the manufacture of calcium carbide, the factories for which are shown above. This picture also illustrates the various types of steel-tower and wood-pole lines built for the transmission and distribution of current.

having increased, it was decided to step-up the pressure from the original 33,000 volts at which it was transmitted to 66,000 volts, and as this demanded replacement of the cables it was decided to grasp the opportunity to replace the original pole system by a line of enhanced strength, although the use of wood for this purpose was to be retained. An ingenious solution to the difficulty was evolved. The original single pole was superseded by a double-pole construction. Two 35-feet poles are spaced 12 feet apart at the base and 7 feet at the top, and carry a 16-feet cross-arm of round timber to receive the insulators. Eight feet below this top arm, a smaller arm for the telephone wires is provided. The posts are not planted in the ground; their stumps rest upon the roughly trimmed surface, and are held in the vertical position by four steel guy wires run from the frame, so that there is no dependence upon the strength of the pole for its support. This type of pole construction has proved entirely successful, and has effectively solved the rotting stump difficulty.

The spans vary in length according to the topography of the country; some are only 150 feet in length, others run up to 3,600 feet—nearly ¾ mile. On all spans exceeding 1,000 feet ⅝-inch steel-cable, with a wire lashed to it is employed, and held by strain-type insulators on a dead end. The majority of the spans are supported by suspension insulators, but owing to the shortage of this type at the time reconstruction was taken in hand, 63,000-volt pin-type insulators had to be used for several miles at the Eureka end.

ELECTRICITY FOR THE CITIES OF MONTREAL AND QUEBEC.

General view of Power-houses 1 and 2 of the Shawinigan Water and Power Company, which has harnessed the Shawinigan Falls. Steel-tower lines transmit current at 100,000 volts to Montreal, and at 50,000 volts to Quebec City. The company supplies electricity for light and power to 114 cities and towns, having a total population of 1,500,000 distributed over an area of 20,000 square miles, through 300 miles of steel-tower. and a network of wood-pole, lines

A transmission system of a vastly different character, noteworthy for one striking engineering achievement, is that